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Application of Fractal Analysis in Evaluation of Urban Road Networks in small sized city of India: Case city of Karimnagar

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Abstract

Transport network structure affects the pattern of urban development and location of social, economic activities, household and employment centres in urban areas. It also affects accessibility and destination choice of travellers. Hence there is a need to evolve an approach for road network development policy for cities which takes into account inequity in road network supply and its impact on urban development through an interactive planning process to incrementally build road networks leading to a sustainable and equitable urban development pattern in the city. In this context fractal analysis offers an alternate approach for rational evaluation of road network system in urban areas.

The present paper attempts to apply the concept of fractal analysis in evaluation of urban road networks for a small city Karimnagar city in the state of Telangana in South India. The study observed that there exists a good relation between the road network lengths and built-up area in the city and thereby using fractal analysis makes a case to rationally identify the requirements of incremental road network spatially taking into account the likely impact of road network augmentation on the development patterns. The paper concludes that fractal analysis is a great potential tool for road network evaluation including addressing the issue of inequity in supply of road networks within urban areas and it is very appropriate as an interactive planning tool to incrementally build road networks in urban situations particularly in developing environments where resources for such investments are scarce.

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Keywords: Fractal Analysis, fractal dimension, True buffer, Road Network, Supply Inequity

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1. Introduction

Road network structure in urban areas plays a vital role in the development of urban areas, which develops the social and economic activities within the urban areas and it is one of the major component in urban development which shapes urban living. Within urban transport, the transport network comprising of road, and rail etc. which influences the pattern & direction of urban growth in the cities. The spatial interactions between the land use and transport system vary with respect to time and space and consider the nature, extent, origins and destination of the urban movement of passengers. The current practice of road network development in transport in Indian cities is devoid of scientific approach and has a norm oriented approach for network provising. In the Master plans in India it is observed that, there are no standard guidelines for circulation pattern in city as shown from Table 1 below:

Table 1 : Land Utilization rate in various Indian cities

City Name	Population (in Lakhs)	Area (in Sq.km)	Road length (KM)	Road Density (km/Sq.km)	Land utilization rate	% of circulation
					Road length/ 1 lakh population	
Hyderabad	38.3	172.0	723	4.2	18.88	7.0
Chandigarh	8.0	114.0	500	4.4	61.84	9.9
Raipur	9.1	12.2	969	79.3	105.60	13.5
Delhi	129.1	701.6	28500	40.6	220.83	22.5
Dhanbad	12.6	355.7	940	2.6	74.89	20.3
Jamshedpur	13.4	149.2	328	2.2	24.53	15.0
Cochin	16.6	330.0	614	1.9	36.99	3.3
Shillong	3.5	25.4	356	14.0	100.47	4.5
Imphal	3.6	30.7	468	15.2	131.95	4.1
Bhubaneswar	8.8	135.0	1600	11.9	181.41	4.3
Puri	2.0	16.3	692	42.4	339.12	13.9
Meerut	14.5	272.0	1391	5.1	95.78	8.4
Kolkata	45.7	1,851	500	0.3	10.93	7.5

As evident there is a need for scientific approach that deals overall structure of the road network and its impact on development pattern & transport quality. In this context it is worthwhile to note that fractal geometry provides an effective and alternate way to for evaluating transport networks and complex properties of geographical features of urban area Most of the research in fractal analysis is limited to area of inequity analysis. No research has been reported on fractal application for road network evaluation in India.

The present paper attempts to demonstrate the application of fractal analysis on evaluation of road network for a small city of Karimnagar in state of Telangana in India. For this research, issues of the existing practice of transport network provisions & its evaluation in Master Plans and in various developments plans/mobility plans in India are analyzed and also reviewed various methods of evaluating road network in urban areas in general & fractal analysis approach in particular. Case city area was selected based on density parameter and rapid growing cities with population size between 1 to 5 lakhs. Karimnagar city in Telangana has been taken to establish the true buffer and identify the relationship between road network and development indicators, its consequent development pattern impact and to apply fractal dimension of road network. To find the inter-relationships between fractal dimension, road network & development pattern to recommend road network augmentation strategies based on inequity in transport network supply. At the end of the study, recommended additional road network and built-up area and evaluation using fractal analysis for urban areas in general and case city in particular

The study is restricted to evaluating existing road network in Karimnagar city of Telangana with having a population of 1-5 lakhs & with area of minimum 35 Sq.Km. Study is restricted in evaluating road networks within the city boundary limits. The study is heavily relies on secondary data (Building block level base map) of the city.

2. Methods of Evaluation of Road network

There are a variety of methods such as shape grammar rules, graph theory, shortest path matrix and fractals for evaluation of road network. Table 2 shows the merits and limitation of each of these methods

Table 2 :Merits and Limitations of existing methods for evaluating road network

Evaluating methods	Description	Merits	Limitation
Shape grammar rules	Shape grammar provides a finite number of rules of how network elements of the same 2 or different type are added to each other.	• Studies the relation between road density and the network loop. • It also provides guidelines / policy for network design.	It does not consider the urban development functions.
Graph theory	Informally a graph is a set of nodes joined by a set of lines or arrows.	• It is majorly used to calculate accessibility between the cities..	Indices based on the number of nodes and links.
Shortest path matrix	Matrix of Minimum Generalized Cost from any Zone i to any Zone j	It takes less time to calculate and its takes less expenditure.	Discriminates types of distributions but not the shapes of the graphs
Geomorpho metry	It is purely based on the geo surface analysis which can be done in GIS.	Quantitative land surface analysis.	Only valid for oriented tree, identical values of the indices for topologically different shapes.
Fractals	Fractals are geometrical objects. (natural / manmade)	It has an intensity approach for describing complex forms like transport network and urban patterns.	Not capable of taking the entire complexity of the problem, sensitive to the way data is summarized.

3. Concept and Features of Fractal analysis

3.1 Concept

Fractal means “broken or fractured” . It is a Latin word and this concept was defined by “Benoit Mandelbrot”. Fractals are self-similar sets of fractal dimension. A pattern is self-similar if it is composed of smaller scales copies of itself. Self-similar means “the same from near as from the far”. Fractals may be exactly the same at every scale and they may be nearly same at different scales. Fractals are also “scale invariant” scale invariance means that fractals appear to be the same at all scales of observations. A fractal often has the following features:

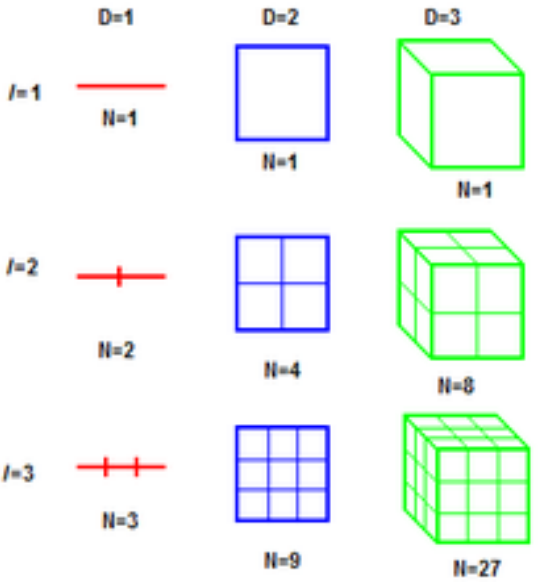
- It has a fine structure at arbitrarily small scales.
- It is too irregular to be easily described in traditional Euclidean geometric language.
- It is self-similar
- It has a Hausdorff dimension which is greater than its topological dimension (although this requirement is not met by space-filling curves such as the Hilbert curve).
- It has a simple and recursive definition.

A city has very a complex subsystems such as population, land use and transportation network. Unfortunately existing methods based on spatial analyses can only provide some results in a certain scale. They cannot evaluate a system from macro to micro as the fractal analysis. Transportation network and other subsystems in a city shows the properties of the fractal named irregular, scale invariant and self-similar. Therefore fractal analysis will be an effective tool for evaluation and representation. Cities and transportation networks have attracted many attentions and been examined for their irregular form and organic growth. Fractal analyses of urban transportation networks fall into two groups those aimed at revealing the regularity and self-similarity of road systems. The policymakers and planners need to test the harmonies between those subsystems or predict them.

3.2 *Fractal city: From complex to organized function*

Believing that a "city or town can be read and analyzed via the medium of its physical form" (Moudon, 1997, Page 7). Researchers have conducted a substantial number of analyses on the fractal nature of the city and the system of cities. These fractal analyses have three main aspects.

- The first aspect is the city as fractal and the fractal property of a city's growth, or `space-filing' process. (Batty et al, 1989; Manrubia et al, 1999; Shen 2002)
- The second group of city fractal analyses goes to a larger spatial scale and investigates the fractal nature of the patterns of urban systems and human settlements. (Appleby, 1996; sambrook and Voss, 2001)
- The third type of research focuses on certain subsystems of the city, such as land-use patterns, built-up area distributions, or transportation networks. (Chen and Luo, 1998; Rodin and Rodina, 2000; Shen 1997)



Fractal studies try to associate the fractal measurement with the function of a city and its urban structure. For example, Shen investigates the relationship between fractal measurement of urban form and urban built-up area as well as urbanized area (Shen, 2002). Chen and Luo link the maturity of a regional transportation network to the fractal measurement of the road system in a region (Chen & Luo, 1998). Batty and Longley encourage further research to explore the relationship between city size, fractal dimension, changing densities and changing form". All these lead to a single conclusion that further fractal research of city and urban subsystems should be devoted to forging informative links between the fractal measurement of a city or its subsystem and the city's functioning and growth process. This type of research is necessary for revealing the close relevance of fractal geometry for real policymaking and planning (Batty and Longley, 1994).

3.3 *Fractal Dimension*

Fractal dimension is an index for characterizing fractal patterns or set by this quantifying their complexity as a ratio of the exchange in detail to change in scale. It is expressed by the following formulae:

$$\boldsymbol{D(Li) = \{[log[l(Ri))/logL(Ri-1)\}/[log(Ri/Ri-1)]}$$

D(Li) = Fractal dimension.
L(Ri) = Length of road network in km in radius of (i).
L(Ri-1) = Length of road network in km in radius of (i-1).
Ri = Radius of the buffer.
Ri-1 = Radius of predecessor buffer zone which are multiple of the radius.

A fractal dimension is a ratio providing a statistical index of complexity comparing how detail in a pattern (strictly speaking, a fractal pattern) changes with the scale at which it is measured. It has also been characterized as a

measure of the space-filling capacity of a pattern that tells how a fractal scales differently than the space it is embedded in; a fractal dimension does not have to be an integer.

Self-similarity dimension = log (number of pieces) / log (magnification factor)

3.4 *Methods to calculate fractal dimension*

The more commonly used methods for estimating the fractal dimension D of objects are.

- *Line segment method*: It is calculated by the walk model method to calculate the fractal dimension of an area.
- *Box counting method*: The total area is divided into squares of equal interval size and counts the fractal dimensions of any city area.
- *Sand box method*: It is measure from a chosen point in the structure how many other points lie in a box of a given size. By performing measurements for increasing box sizes.
- *Mass radius*: The total area is divided into circles of equal interval to calculate FD of any city. It is mostly used for radial cities.
- *Dividers method*: It assumes we have a ruler of length δ and that we can cover the entire curve by a number of ruler lengths.

3.5 *Calculation of Fractal dimension in Mass radius method*

There are two reasons for choosing fractal geometry method for this research study.

1. The road and built-up area of the satellite towns around a big city are similar in spatial distribution, which means they have self-similar attributes.

2. By using fractal analysis more quantitative spatial information to describe their relationship can be acquired.

- *Road pattern as fractal:* $D(Li) = \{\log[L(Ri)/logL(Ri-1)\}/[\log(Ri/Ri-1)]$
- *Built-up area as fractal:* $D(Bi) = \{\log[B(Ri)/logB(Ri-1)\}/[\log(Ri/Ri-1)]$
- *Road width as a fractal :* $D(RWLi) = \{\log[RWL(Ri)/logRWL(Ri-1)\}/[\log(Ri/Ri-1)$
  4 categories of road are taken (3.5m, 3.5 – 7m, 7m-12m, above 15m) and calculated the road density
- *Access points as a fractal=* $D(Ai) = \{\log A(Ri)/logA(Ri-1)\}/[\log(Ri/Ri-1)$

Where D(Li) = Fractal dimension of road length in buffer zone of radius I
L(Ri) = Length of road network in km in radius of i.
L(R i-1) = Length of road network in km in radius of i-1.
Ri = Radius of buffer zone
Ri-1 = Radius of predecessor buffer zone which are multiples of 0.4.
If i=0.8, i-1 = 0.4. and so on.

3.6 *Relation analysis between road network length & build up area as fractal*

Fractal analyses have three main aspects.

- City as fractal and the fractal property of a city's growth, or `space-filing' process.
- Fractal analyses goes to a larger spatial scale and investigates the fractal nature of the patterns of urban systems and human settlements.

- Focuses on certain subsystems of the city, such as land-use patterns, built-up area distributions or transportation networks.
- The patterns are closely related to urban growth and built-up area increase. This relation is analysed using the fractal dimension tool.

$$L^1 \propto S^{1/2} \propto V^{1/3} \propto M^{1/D}$$

Where **L** is the length of geographical entity, **S** is area, **V** is the volume and **M** is any dimension and **D** is fractal geometry

4. Application of Fractal Analysis to City of Karimnagar

4.1 Background

Karimnagar is a city and a Municipal Corporation in the state of Telangana located on the banks of Manair river, a tributary of the Godavari river. It is the administrative headquarters of Karimnagar District and the city is 162 kilometres north away from Hyderabad, the capital city of Telangana. It is a major business center and it is emerging as a major educational hub. As per 2011 census, Karimnagar city had a population of 299,660 in which males constitute 51% of the population and females 49%. It has an average literacy rate of 86.75%, which is higher than the national average of 74.04% within this male literacy is 92.61%, and female literacy is 80.79%. The city is connected to major cities and towns by means of road and railways. State highway-1 which passes through the city connects with the Hyderabad-Karimnagar-Ramagundam highway coal belt corridor. TSRTC operates buses to various destinations from Karimnagar bus station of the city. Karimnagar railway station provides rail connectivity to the city.

*4.*2 Identification of true buffer

Buffer radius plays a vital role in understand the relationship between the built environment with road network and to identify which buffer radius will helps to study these parameters. For this a separate analysis has been carried out in the case city. The figures 1 below shows the percentage of change in built up area with change in different buffer radius

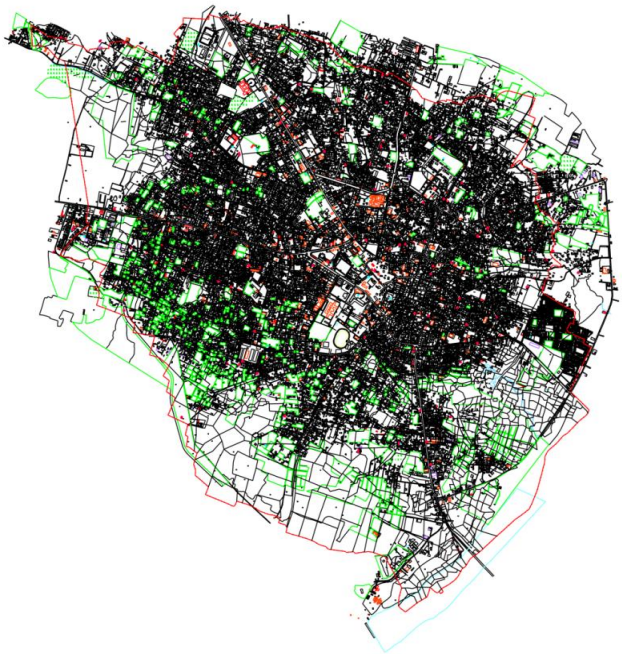


Fig 1: Karimnagar city Map

Table 3 shows the details of buffer interval at100m, 250 m, and 500m respectively

Table 3 : Identification of buffer interval

Buffer interval	500M	250M	100M
Computing Time	7 hrs	10 hrs	12 hrs
True Fractal Dimension	1.65	1.5	1.5
Robust	1	1.5	1.25

5. Impact of buffer interval on road network and development Indicators

From the analysis it is observed that, increase in buffer interval leads to decrease in the build-up area. As moving away from the city center to the outside area, the build-up area of the city will decrease due to the residing population in the outer areas will be less with comparing to inner areas.

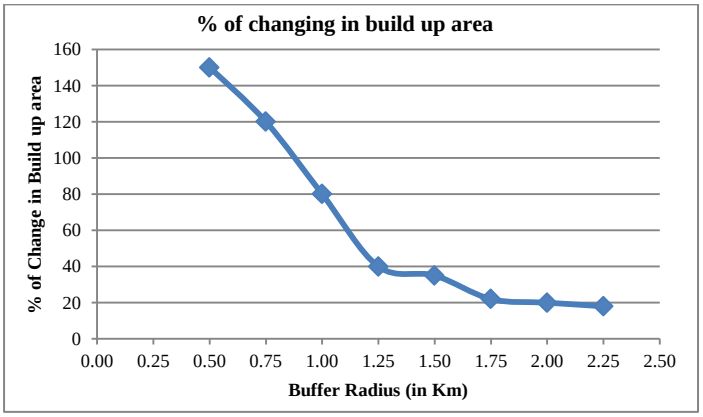


Fig 2: % of changing in build-up area

In this study built-up area was further divided into three major land uses to have an in detail segregation analysis. It is observed that with increase in buffer interval while the residential slope decrease slowly the commercial settlements have a negative slope.

Road network length parameter exhibits a negative slope as increase of buffer Interval which is observe generally in small size cities, as moving from the city center the city road network length will decrease due to the decrease of local and collector roads length.

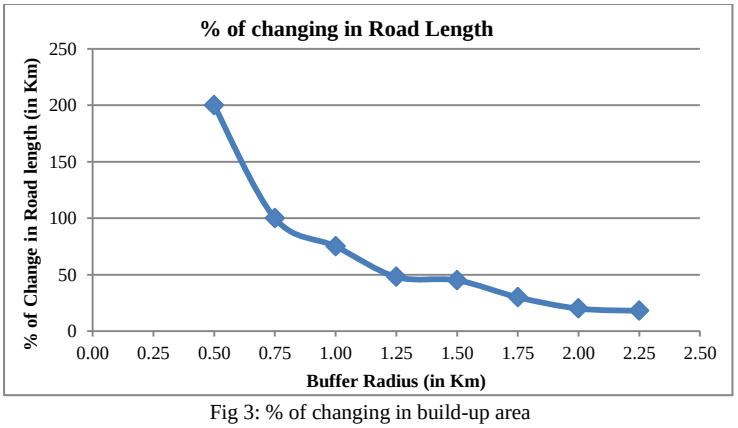
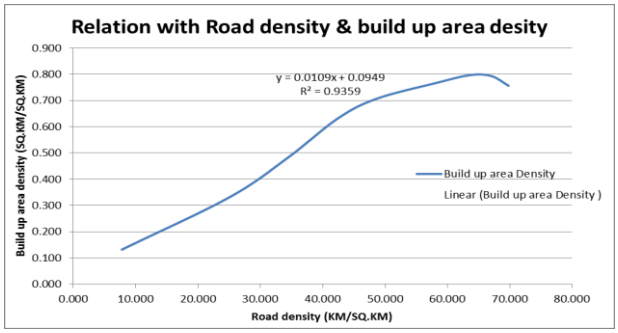


Fig 3: % of changing in build-up area

- Access points (Number of junctions) have a negative impact in the increase of buffer interval. This indicates that there will be less intersection in the outer areas with comparing to inner areas and this also a general phenomenon which will be observed in the Indian cities .
- As buffer interval increases, the average distance between the two junctions (link length) will increase. There is good correlation of 0.98 between the various road lengths (below 3.5, 3.5 to 7.0, 7.0 to 12.0 and above 12M) and buffer interval. As the buffer interval increase, the various road widths will increase except the local roads (below 7.0M) which is generally observed in any Indian city
- Increase in buffer intervals has a positive result in the weighted average speed of the city. As it is observed, there is good relation between buffer interval, road network and development indicators with 0.95 correlation.

6. |Impact of Road network and Development Patterns

From the intra-relationship analysis it is observed that the road network length has direct relation with built-up area. As it is observed, increase in road length will increase the build-up area in the city up to a certain point, after that it will have a negative impact. It is also identified that there is a good inter-relationship established between built up area and various land use (Residential, Commercial, Other land use). As built-up area increases residential area also increase at the same level (slope), commercial and other land use exhibits a constant slope after a certain point, even increase in built-up area. As it is identified there is a good relationship between road length and various road widths (below 3.5, 3.5 to 7.0, and 7.0 to 12.0 and above 12M). As the road length increases above 12M and 7.0M, road lengths also increase at the same slope but 3.5 to 7.0M and below 3.5M road length have a negative slope after a certain point even increase in road network length. Increase of road network length will decrease the congestion index. As built-up area increase, speed also increase till the breakeven point, after that there will be a negative impact with decline in speed levels. Desirable speed observed for Karimnagar city is 28Kmph. It is also identified there is a good relation between the network indicators and development indicators with having a correlation value of 0.9.



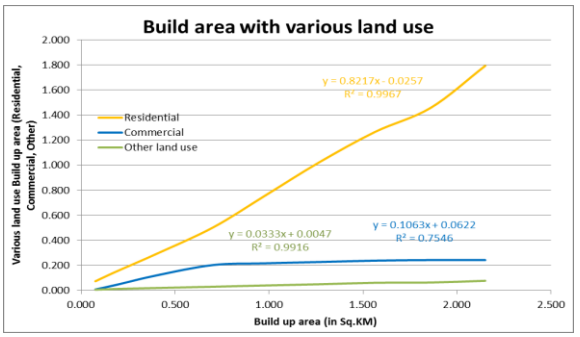
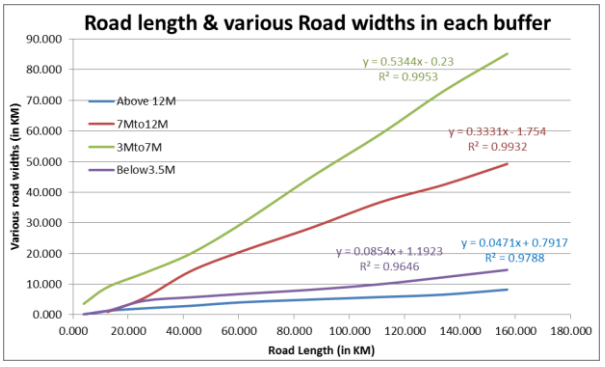


Figure 1 : Road density with Built up area density Figure 2: Built up area with various land use



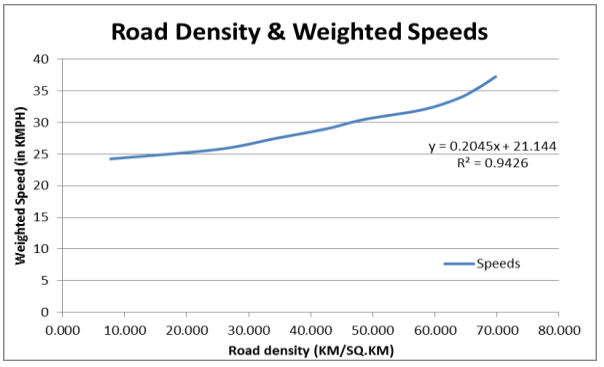
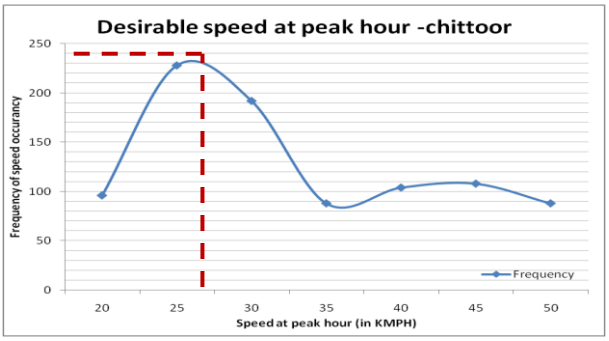


Figure 3 : Road length with various road widths in each buffer Figure 4: Road density with weighted speeds



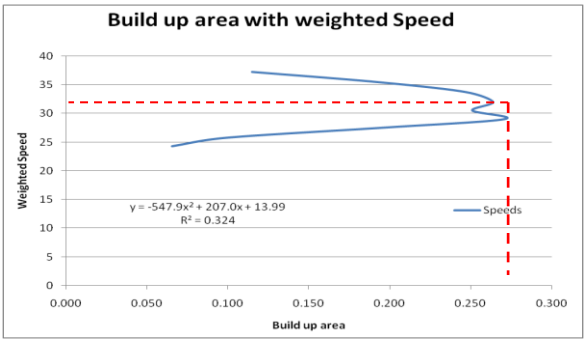


Figure 5 : Desirable speed at Peak hour in Karimnagar Figure 6: Built up area with weighted speed

7. Inequity analysis of Karimnagar city

Form the analysis it is observed that the true fractal dimension of the city is identified at 1.5 for Karimnagar city. True fractal dimension is identified mainly on two bases

1. City is a 2 dimensional element which is having 2 directions in growth. So the true buffer will be within the range of 1-2 by this condition the values which are less than 1 and above than 2 are considered.
2. Each buffer interval and its respective indicators fractal dimension is calculated as a concept of true fractal dimension modal value where a buffer is having all the indicators with in the same fractal dimension.

- The buffer which is having a fractal dimension less than 1.5 value there are need to be augmented and the value beyond the 1.5 are restricted to no further development. Green filed model is developed between the fractal road length and the population / 1000 to augment the network in the inequity buffers.
- There is a good relation established between fractal dimension (road length) and the road length of the city with having a correlation value of 0.88. Using this relation a model has been developed to augment the road length for the assed fractal dimension.
- As it is observed in the earlier analysis that there is a good relation between the road network lengths and built-up area in the city and based on that a model has been developed to augment the road network length with estimated built-up area.
- Identifying the required build up area & road network using the model, Inter-relationship model has been used to assess the various land use under built-up area and various road widths lengths under road network length.
- Based on the increased road network length and built- up area the city speeds were estimated and it was compared with desirable speed 30Kmph which is recommended in Wilbur smith 28 cities.
- After augmentation of road network and built-up area the desirable speed is estimated at 30Kmph and the estimated desirable speed is within the acceptable range.

Table 4 : Buffer interval wise True fractal dimension

Buffer radius	Fractal dimension of Road length	land use promote	No more development	land use restricted
0.5	1.58		X	
0.75	1.76			X
1	1.71		X	
1.25	1.55		X	
1.5	1.86			X
1.75	1.56		X	
2	1.28	√		
2.25	1.34	√		

*Green colour shows the additional development can be possible in those buffers and
*Red colour buffers are restricted for further development

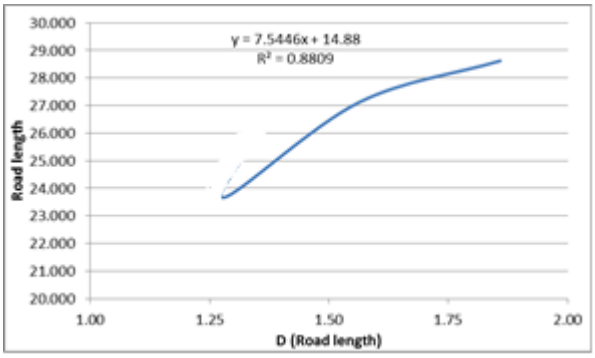


Figure 7 : Fractal dimension of road length with road length

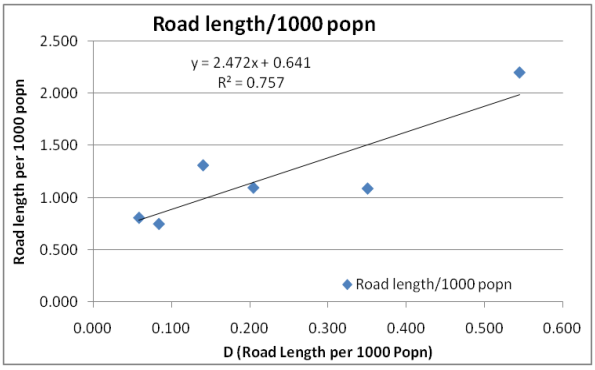


Figure 8: Fractal dimension of road length per 1000 population with road length per 1000 population

Table 5 : Buffer interval wise existing & additional road network & built - up area

Development indicators	Buffer interval			
	2		2.25	
	Existing	Additional	Existing	Additional
Road length	23.69	4.4	25.72	8.65
Build up area	0.29	0.15	0.3	0.2
Residential	0.19	0.08	0.34	0.12
Commercial	0.0	0.06	0.0	0.07
Other	0.0	0.01	0.01	0.01
Below 3.5M	2.37	2.74	2.68	3.38
3.5M - 7.5M	14.76	0.42	13.58	1.21
7.5M - 12M	5.75	1.75	7.62	1.97
above 12M	0.81		1.83	2.1
	Existing	Impact	Existing	Impact
Speed	32	25.33	35	25.67
Congestion Index	-0.143	0.095	-0.7	0.83

8. Summing up

In this present paper, mass radius method is considered to measure the fractal dimension and it is observed that there is a strong relationship identified between the road network indicators with fractal dimension and correlation between the road network with built-up area indicator. A brown field model is developed where there is no chance for development in the core areas and there is only scope for develop in the middle and prei urban areas. With reference to the existing characteristics of road length and built-up area, additional requirement of road network in the city by maintaining their density decay curve with respective to population density per hectare in each buffer.
The major advantage of the fractal analysis is it is a straight forward model and it takes less time and cost and it also

helps in the preparation of masterplan (network augmentation section). This model is very useful for smaller size cities in developing countries.

The analysis has confirmed that, need to bring out the similarities in road network, minor junctions and built-up area uniformity. In the case city deficiency observed in the higher order road functionality system is also highlighted. The analysis has been used as criteria for promoting land use/ reducing land use in the buffer of the city based on the true fractal dimension. The rapidly changing in outer areas of cities can therefore be examined through the estimation of fractal dimension and the change of its value through time. It is concluded that this approach is very useful for evaluating road networks of small size cities in developing countries.

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