Urban Sprawl Management: Need for an Integrated Spatial Planning Support System

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Abstract

The pressures on the natural resources are increasing day-by-day so as to cater to the rising urban population while towns and cities are expanding hay-way to meet these demands. At this juncture it is also important to understand the implications of such change in the natural environment over the ecosystem so as to better manage the resources. The phenomenon of urban sprawl is potentially observed as a threat for achieving sustainable urbanisation. Hence, it is very essential to understand the phenomenon of urban sprawl especially with the perspective of a developing country. Further, the problem of urban sprawl is known to be an outcome of improper planning, inadequate policies and lack of good governance due to various reasons. The inability of the planning machinery to visualise probable areas of sprawl and its growth is persistent with the lack of appropriate spatial information and indicators. Added to this, is the inability of the planning and administration to capture the feedbacks arising out different decisions, essentially with lack of dynamic spatial models with feedback mechanisms. Furthermore, inappropriate policy decisions are fuelling sprawl as no mechanism to evaluate for different policy implications, with the lack of spatial planning support systems to test and validate different policy options. With the need for sustainable development it is essential to integrate the various factors responsible for dynamic process and establish the complex relationships amongst them. Geospatial technologies offer adequate opportunities in studying, quantifying and monitoring urban systems both in spatial and temporal aspects. However, the geospatial modelling *per se* is still inept to handle dynamic geospatial simulations. This lacuna is well bridged with the agent-based modelling. The understanding and quantification of urban systems using systems approach and multi-agent systems would capture the dynamics of the system and be useful to simulate the likely changes in future. Thus, in the present context, with the escalating problem of the urban sprawl, the challenges for future research is to arrive at an integrated spatial planning support system to effectively plan, review and evaluate the different policy options while capturing the dynamics involved.

Keywords: Urban Sprawl, Urban Dynamics, Geographic Information Science, System Dynamics, Complex Systems, Cellular Automata, Agent-based Modelling, Multi-Agent Systems, Geospatial Modelling and Simulations, Spatial Planning Support Systems

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1 General

1.1 Urban Areas and Urban Growth

An urban area is defined based on the number of residents, the population density, the percent of people not dependent upon agriculture, or the provision of such public utilities and services. The term 'urban' has its origin from the Roman name *Urbanus* which meant 'city dweller' in Latin. The precise definition of an urban area can vary from country to country. Some countries define an urban area as any place with a population of 2,500 or more while some countries set a minimum of 20,000 for this criterion. In general, there are no universal standards and so each country develops its own set of criteria for distinguishing urban areas. In India, an area is designated as urban if the population is more than 5000 with a population density of more than 400 persons per sq. km and at least 75 percent of the population are involved in non-agricultural occupations (Shashidhar, 2001). India's urban population is currently growing at about 2.3 percent per annum. With an unpremeditated population growth and migration, an increased urban population and growth in urban areas is inadvertent. Urban growth, as such is a continuously evolving natural process due to population growth rates (birth and death). The number of urban agglomerations and towns has increased from 3697 in 1991 to 4369 in 2001. It is projected that the country's urban population would increase from 28.3 percent in 2003 to about 41.4 percent by 2030 (United Nations, 2004). By 2001, there were 35 urban agglomerations / cities having a population of more than one million up from 25 urban agglomerations in 1991. The magnitude of urban growth taking place in India at only few urban areas is evident from the proportion of the urban population in these 35 urban agglomerations / cities to the total urban population of the country. It is seen that these 35 urban areas account for about 38 percent of the total urban population, thus indicating the magnitude of urbanisation prevailing in the country. This clearly indicates the magnitude of concentrated growth taking place in large urban agglomerations, which has paved way for urban sprawl.

1.2 Urbanisation and Sprawl

Urbanisation is a form of metropolitan growth that is a response to often less understood implications of technological, economic, social, and political forces and to the physical geography of an area. Urbanisation, as such, is not seen as a threat to the environment and development, but it is the unplanned urbanisation and subsequent urban growth, or the sprawl that affects the land-use of any region prone to extensive urbanisation with loss of prime agricultural lands. Indian economy

is mainly agrarian (contribution to GDP is about 28 percent) with about 70 percent of the population reside in rural areas. Lopsided developmental activities have lead to large-scale deforestation and about 30 percent of land has become barren or unproductive. It is thus imperative to study and bring out the intricacies and implications associated with the problem of unplanned urban growth or the sprawl.

Urban sprawl is the outgrowth of the urban areas caused by the uncontrolled and uncoordinated urban growth. Sprawl is also considered to be an unplanned outgrowth of urban areas along the periphery of the cities, along highways, and along the road connecting a city. Towns and cities are expanding in certain pockets with a change in the land use along the highways and in the immediate vicinity of the cities due to ad hoc approaches in planning and decision-making. This dispersed development outside of compact urban and rural centres along highways and in rural countryside is also referred as sprawl. Sprawl generally infers to some type of development with impacts such as loss of agricultural land, open space, and ecologically sensitive habitats in and around the urban areas. These regions lack basic amenities due to the unplanned growth and lack of prior information and predictions of such growth during planning, policy and decision-making.

The sprawl results in the engulfing of villages into peri-urban areas, peri-urban areas to towns and towns into cities. However, in such a phenomenon of development to have basic infrastructure, regional planning requires an understanding of the sprawl dynamics. Nevertheless, in majority of the cases there are inadequacies to ascertain the nature of uncontrolled growth. Due to lack of prior planning, coordinated decision-making and visualization of the outgrowths, these are devoid of basic amenities like water, electricity, sanitation, etc. and also results in inefficient and drastic change in land use affecting the ecosystem and thus threatening the sustainable development of the region.

1.3 Urbanisation and Development - Towards Sustainable Urbanisation

The emergence and advancements in technology, has transformed societies into socio-technical systems, with huge dependencies on the information and communication technologies (ICTs). This has further lead governments to continuously change and adapt to fulfill all the obligations towards

its stakeholders. An imminent urbanisation coupled with economic development has transformed societies and cultures apart from the landscapes, and the natural environment.

A key challenge faced by most nations today is to 'sustain' the economic growth rate - development along with minimal impact on the environment. In the recent years 'development' and 'urbanisation' has almost become synonymous especially in the developing countries. Further 'development' *per se* is mostly associated with economic development, which most nations promise to deliver to its citizens. Urbanisation, is also common phenomenon which most of the developing nations are experiencing, which has led to the rise of large metros along with its slums and squatters. At the same time an alarming concern is also about the depleting natural resources, increasing pollution levels and associated environmental hazards apart from the rising urban-rural and rich-poor divisions; a host of environmental and socio-economic factors that have become important challenges of the recent times.

In this regard, it is essential for authorities concerned with administration and management of urban areas and urban development to adopt integrated approaches in regional planning while addressing the needs of its stakeholder's and manage the resources sustainably. This also necessitates proper planning to manage the urban growth and to mitigate the pressures on natural resources and environment while catering to the needs of the economy that sustains these urban areas. It is this philosophy that drives, sustainable development, essentially addressing to balance both economic development and environment, not only for the present but also for the future generations.

In the recent years 'sustainable development' is a commonly used terminology among various regional, national and international agencies subsequent to the publication of Brundtland report in 1987. The Agenda 21 of Rio 1992, has endorsed the need for sustainable development. Highlighting the tenets for sustainable development, Reddy (2004) emphasized the need for strategies addressing 'equity, economic efficiency, environmental soundness, long-term viability, self-reliance and peace' for regional and nation's sustainable development. The sustainable development is defined as, 'development that meets the needs of the present without compromising the ability of the future generations to meet their own needs' (World Commission on Environment and Development, 1987). In order to sustain development, the supply and quality of major consumables and inputs to our daily lives and economic production - such as air, water, energy, food, raw materials, land, and the natural environment needs to be taken care of. Land is essential

because our food and raw materials originate from them and is a habitat for flora and fauna. Similar to other resources, it is a scarce commodity. Any disturbance to this resource by way of change in land use e.g. conversion of forest land, agricultural land into built-up, is irreversible. The use of land unsuitable for development may be unsustainable for the natural environment as well as to the humans.

Urban growth patterns resulting in sprawl are 'unsustainable', with the current consumption surging ahead of regions' carrying capacity and leading to depletion of natural resources for future generations. The need for managing urban sprawl also arises out of the global concerns of achieving sustainable urbanisation. Sustainable urbanisation is a dynamic, multi-dimensional process covering environmental as well as social, economic and political-institutional sustainability (UN-Habitat, 2002).

Proper implementation of master plans / development plans is a critical aspect in the regulated development of urban areas. Although 1200 master plans / development plans for important towns and cities have been prepared so far, their implementation has not been satisfactory due to a variety of reasons, which in turn have resulted in mushrooming of slums and squatters, unauthorized and haphazard development and above all environmental degradation and transportation problems within and around the urban areas. Further, the development plans / master plans are mostly documents prepared with limited forecasting capabilities without capturing the entire dynamics and are generally not responsive to dynamic problems and responsive to policy changes. It is therefore necessary to enable the administrators and planners to graduate and equip with better understanding, methods and tools to tackle the problem of urban sprawl.

Understanding the sprawl processes, its dynamics and modelling provide an insight of future growth trends, which is useful for effective resource utilization and infrastructure planning. The efficiency of urban settlements largely depends on how well they are planned; how well they are developed economically and how efficiently they are managed. It is thus essential to undertake a study to understand the dynamics of sprawl and evolve a dynamic spatial planning support system.

2 Background and Literature Review

2.1 Origin and Evolution of Towns and Cities

Introspection on the origin of towns and cities has to be traced back to the human evolution about 3 million years back. Our distant ancestors lived a very hard existence as hunters and gatherers until the early civilisations started around 8000 years ago. Different levels of human organisation characterised by technological, economic, social and political patterns are the factors that brought about the origin and evolution of cities before the modern epoch of urbanisation (Sjoberg, 1965).

In the first level, the pre-urban and pre-literate human society was mostly hunters and gatherers with little or no surplus food. Consequently, the society had little or no specialisation of labour or distinction of class. Slowly through the advances in technology and organisational structure, human societies evolved in to slightly complex societies through settlements in villages. With the progress of time, humans learnt to cultivate and subsequently communities evolved that could support more people with food. With the knowledge of cultivating plants, lighting fire, inventing wheel, making tools, humans advanced by leaps and bounds. This second level of human organisation is attributed to the knowledge of humans to cultivate thereby creating a surplus of food. This pre-industrial civilised society is also characterised by the art of writing to make inscriptions, maintain and record law, literature, and religious beliefs and the ability to harness energy from wind and water sources for sailing in seas to grinding grains to make use of water power. By around 2500 years BCE there were towns and cities like Harappa and Mohenjo-daro. Within 500 years BCE kingdoms and cities emerged worldwide where most of the civilisations originated mostly in the river valleys. This included the cities of India, Mesopotamia, Egypt, China, etc. During the next one millennium the world saw a host of religions that came up to have a significant impact in human evolution. Meanwhile, cities expanded, kingdoms rose and fell, wars were fought, and the humans learnt to harness the natural resources incessantly and mercilessly. The post-industrial revolution cities characterised by mass literacy, a fluid class system and the tremendous technological breakthrough to new sources of inanimate energy that sustained the industrial revolution form the third level of complexity in the human organisation (Sjoberg, 1965).

The industrial revolution during eighteenth and nineteenth century is seen as a major cause for the current growth and sustenance of towns and cities. The developments during the industrial revolution between 1750 and 1830 CE transformed most of north-western Europe from a largely rural and agrarian population to a town-centric society engaged increasingly in factory manufacture, trade and commerce. The post industrial revolution era also saw the enormous upsurge in people moving from rural to urban settlements.

As most of the north-western Europe became industrialised, the faster was the urbanisation. In the more advanced countries, urbanisation seemed as a consequence of industrialisation, although more these countries urbanised, industrialisation and technological innovations also got enhanced significantly. A strong positive reinforcing feedback emerged with the industrialisation and urbanisation in the advanced countries alone. Contrastingly enough, the industrialisation and subsequent urbanisation did not catch up in the developing and under-developed countries as in the developed countries until the mid-nineties. Of late, the developing countries have seen tremendous upsurge in their urbanisation and urban population growth rates, especially with the number of cities and urban agglomerations having a population of more than a million populations has increased significantly over the recent decades. This upsurge has not been solely as a consequence of industrialisation alone in these countries, but also due to the falling agriculture produce and other factors in rural areas, like livelihood, inducing migration of large populations into urban areas in search of better livelihood (Harris, 2005).

In industrialised countries the growth of urban population is comparatively modest as population growth rates are low and over 80 percent of their population already live in urban areas. Conversely, developing countries with higher growth rates are in the middle of a transition. The exceptional growth of many urban agglomerations in many developing countries is the result of a threefold structural change process: the transition away from agricultural employment, high overall population growth, and increasing urbanisation rates (Grubler, 1994). Unlike in developed countries, where the problem of sprawl has to be addressed in terms of transport, energy, land use, and environment, developing countries are faced with the problem of increasing urban poverty levels, higher population growth rates and rising numbers of slums or squatters resulting out of sprawl. It is in this context that the study on urban sprawl gains importance.

2.2 Urban Growth, Urbanisation and Urban Sprawl

It is very much apparent that cities had evolved more than few millennium ago, while some grew and perished, urban growth was prevalent and not urbanisation. It is essential to clearly distinguish from the growth of cities from the thousands of years to the more recent urbanisation. On the distinction of urbanisation and urban growth, several authors have put forward their viewpoints. Cautioning that attributing simply the growth of cities to urbanisation, Davis (1965) notes that urbanisation refers to the proportion of the total population concentrated in urban settlements, or else the rise in this proportion. It is argued that since urbanisation would account for the total population composed of both urban and rural, the proportion urban is a function of both of them. Accordingly cities can grow with out urbanisation provided the rural population grows at an equal or greater rate. The transformation of human settlements from a spread-out to compact urban centres is a change that can be traced, but the growth of cities has no inherent limit and so are the boundaries. Such growth could continue even after everyone was living in cities, as in cities of already urbanised developed countries, through sheer excess of births over deaths (Davis, 1965).

The process of urbanisation is fairly contributed by rural-urban migration leading to the higher proportional population growth of urban-rural and infrastructure initiatives, resulting in the growth of villages into towns, towns into cities and cities into metros. In developed countries of north-western Europe and North America, urbanisation is already at its peak, with little or no further urbanisation possible, as the scope for rural-urban migration is minimal. Furthermore, it is the urban population *per se* that grows and not the proportion of urban to rural population. With the extensive urbanisation followed by industrialisation, the compact and densely populated cities emerged during the last century. Over the last century, these countries saw the emergence of large metropolitan cities. What has been intriguing to the urban planners, researchers, managers and administrators is in spite of the saturated and stagnated urbanisation, the cities are *continuing to spread* (Batty et al., 2003). As the cities grew in population, transportation got affected. The affluent also aided by individual transportation moved towards the outskirts thereby minimising costs at the central business districts, inducing the spread of cities (Marathe, 2001). At times, the city authorities provided better transportation from the core to the outskirts and along the periphery, which encouraged people to move outskirts also inducing sprawl. In other words, be it either better transportation or the population growth, the cities expanded consuming neighbouring agricultural

lands and affecting ecologically sensitive habitats. This phenomenon of urban sprawl is being witnessed, studied and documented in most cities of north-western Europe and North America even after reaching the stagnation and saturation levels of urbanisation. The problem of sprawl is now being addressed through extensive studies and policy recommendations in the European Union (Gayda et al., 2005) and United States of America (TRB, 2002).

In 1800, only 3 percent of the world's population lived in urban areas. By 1900, almost 14 percent were living in urban centres, and only 12 cities had 1 million or more inhabitants. In 1950, 30 percent of the world's population resided in urban centres and the number of cities with over 1 million people had grown to 83. The world has experienced unprecedented urban growth in recent decades. In 2000, about 47 percent of the world's population lived in urban areas. Now, there are 411 cities over 1 million. More developed nations are about 76 percent urban, while 40 percent of residents of less developed countries live in urban areas. However, urbanisation is occurring rapidly in many less developing countries. According to Population Research Bureau (2005) it is expected that 60 percent of the world population will be urban by 2030, and that most urban growth will occur in less developed countries.

The implications of sprawl are not only on the surrounding neighbourhood with loss of agricultural lands or ecological habitats, but on the basic amenities like, transportation, water supply and sanitation, energy, etc. within the inner core of the city also. As sprawl advances, the city notifies overtime these areas as a part of the extended city itself, thus it will become the onus of the city administrators to cater for the rising travel demands, water supply and sanitation, energy needs, etc.

The magnitude and nature of urban sprawl is quite different in the developed countries than to that of a rapidly developing and largely rural-agrarian populated country like India. The problem of sprawl is magnified in the developed countries after reaching saturation levels of urbanisation. Conversely, most of the developing and under-developed countries are now urbanising rapidly and already prone to the problem of sprawl at an even worse magnitude. A significant difference in the urbanisation patterns of developed and developing countries is that of population densities. The developed countries embraced urbanisation after industrialisation wherein the population growth rates and densities were lower, with a prosperous economy and technology to support. Conversely, developing countries are having high population growth rates and densities, in the midst of economic development, lack of basic amenities, urbanisation is taking place at a rapid rate. In India,

already 28 percent of the population live in urban areas and these cities are expanding like never before, with inadequacies in facilities for transportation, water supply and sanitation, energy demands, etc. With a moderate economic activity and large populations in unorganised sectors of employment and inadequate housing the rise of slums and squatters in urban areas seem inevitable.

Typically the planning machinery and administrators are less equipped to address the issues of sprawl. Concentrated economic developmental activities in few localities have implications of rural-urban migrations that lead to skewed growth. The city planning is mostly addressed at catering to the future projected population and the facilities the civic authorities need to cater for that forecast of population, which are normally a static master plans or development plans. These plans are also less equipped to review and evaluate any policy decisions dynamically so as to visualise the potential implications of a policy directive and also the regions of potential sprawl. It is in this context, that the planning machinery and administrators need to be informed of the possible areas of sprawl to take corrective actions to mitigate the implications. In this regard, future research has to contribute towards a deeper understanding of the urban sprawl phenomenon, capturing the dynamics, modelling it and designing a spatial planning support system to visualise, review and evaluate the various policy options so as to have effective methods and tools to mitigate the problem of sprawl.

2.3 Revisiting the Definitions of Urban Sprawl

Until 1960s, the problem of urban sprawl was not studied / documented in already urbanised economically advanced countries. Although, Davis (1962) notes the 'deconcentration of cities as they become more urbanised', this was not formally termed as sprawl then. The Transportation Research Board (TRB) of the United States of America, in one of the recent and authoritative definitions, ascribe sprawl to exhibit 'deconcentrated centres' and grow in the neighbourhood (TRB, 2002). The problem gained importance only in late 60's and early 70's, mostly in the USA and north-western Europe. And since then there has been significant research and debates on this topic.

Several authors (Batty et al., 1999; Batty et al., 2002; Torrens and Alberti, 2000; and TRB, 2002) and organisations have attempted to define 'sprawl' since the problem of urban sprawl has been acknowledged for nearly fifty years. A working definition of urban sprawl was arrived at after reviewing different definitions of urban sprawl. Sierra Club (1998), defines sprawl as low-density

development beyond the edge of service and employment, which separates where people live from where they shop, work, recreate, and educate - thus requiring cars to move between zones. This definition ascribes sprawl induced directly by the location of work-home and aided by individual transportation (cars), the phenomenon more prevalent in the United States of America.

Batty et al., (1999) considers urban sprawl in relation to the contemporary urban growth consisting of three interrelated problems of spatial dynamics: the decline of central or core cities which usually mark the historical origins of growth; the emergence of edge cities which compete with and complement the functions of the core; and the rapid suburbanisation of the periphery of cities - core and edge - which represent the spatially most extensive indicator of such growth.

Further, Torrens and Alberti (2000) note that sprawl is characterised by uniform low-density development, which is often uncoordinated and extends along the fringes of the metropolitan areas invading prime agricultural and resource lands. Also, they indicate that such areas are over reliant on the automobile for access to resource and community facilities with these areas regarded as aesthetically displeasing.

The study of urban sprawl and its implications have been addressed by Transportation Research Board (TRB) (1998, 2002) and Sierra Club (1998). TRB (2002) explains sprawl as the spread-out development that consumes significant amounts of natural and man-made resources, including land and public works infrastructure of various types. Sprawl also adds to overall travel costs due to increasing use of the automobile to access work and residence locations more widely spaced due to the sprawl phenomenon. Furthermore, sprawl appears to de-concentrate centres and takes away from the multiplicity of purpose that neighbourhoods once delivered. Yet sprawl has benefits. It offers access to less-expensive housing and opportunities for homeownership at the periphery of metropolitan areas. It provides congestion management in automobile-dominated metropolitan areas by creating the suburban-to-suburban trip and by better equalizing the percentages of the commuting population involved in reverse and forward commutes.

Recently Batty et al. (2004) termed sprawl as ‘uncoordinated growth’, the unplanned incremental urban growth which is unsustainable. Noting that sprawl is a consequence of simultaneous population growth and better transportation from the core to edge, they question it as a typical

chicken and egg conundrum of what comes first: better transportation or population growth; or population growth followed by better transportation? Obviously, it is a difficult paradigm to ascertain whether it is population growth or transportation that leads to sprawl.

A working qualitative definition for the present research based on earlier discussion of urban sprawl could be as the outgrowth of the urban areas caused by the 'unplanned' and 'uncoordinated' urban growth. In an already urbanised and developed country like England, the sprawl can be thought of chicken or egg problem. However, in the context of a rapidly urbanising and developing country like India wherein the population is largely agrarian with high urban population growth rates and a booming economic activity, sprawl is not only a chicken and egg problem, but there are a host of factors that are contributing to the complexity for sprawling towns and cities.

2.4 Studies on Urban Sprawl

The studies on urban issues have been of interest to geographers, sociologists, urban planners, administrators, researchers and everybody associated with this. Since the industrialised nations urbanised first and so the problem of sprawl is recognised earlier in these countries than developing countries, much of studies are reported from these countries. Initially most of the studies concerning urbanisation and sprawl have been addressed in relation to the population growth and the spatial extent of the urban areas. Subsequently most of these studies have dealt the problem of sprawl in relation to either transportation, demography, economics, energy, land use, vehicular emissions, climate or safety. Barring a few studies in the USA [94] and north-western Europe [35], the problem of sprawl has been tackled mostly in isolation with respect each of the disciplines and not in an integrative approach. The study of urban sprawl and its implications have been addressed by TRB (1998, 2002) and Sierra Club (1998). TRB (2002) explains sprawl as the spread-out development that consumes significant amounts of natural and man-made resources, including land and public works infrastructure of various types. Ascribing the resource impacts of sprawl in terms of costs, these impacts have been classified as: land conversion, water and sewer infrastructure, local road infrastructure, local public-service cost and real estate development costs. The personal costs of sprawl have been mainly attributed to travel miles and costs, with the sprawl affecting the quality of life and hence the urban decline.

Ciscel (2001) examined sprawl by quantifying three components: the jobs, business and housing; commuting; and government infrastructure capital costs and notes that sprawl raises the costs of operating urban infrastructure and hence leads to economic inefficiency. Brueckner (2001) attributes the spatial growth in the USA to: rise in population, rise in incomes and falling commuting costs. It is further argued that urban growth is in response to these fundamental forces and hence urban growth is not socially undesirable. Any market failures distorting the fundamental forces, can lead to improper allocation of land between agricultural and urban uses.

The urbanisation in advanced countries has reached stagnation, while the presence of sprawl has become more obvious and hence various studies have been undertaken to address them in the recent times in developing countries. Subsequently, most of the studies and definitions are in relation to the economically advanced countries wherein the levels of urbanisation are different to those in economically advancing and rapidly urbanising countries like India, with high population densities adding adequate complexities to the problem. It would therefore become essential to address the problem of sprawl by appropriate studies in relation to economically advancing country like India thereby facilitating a greater understanding of the process with a different dimension to the existing definitions of urban sprawl as seen in advanced countries.

2.4.1 Studies in India

Among the earlier investigations on India's urbanisation are documented in Turner [95], which includes studies by Davis (1962), Bogue and Zachariah (1962), Brush (1962) and others. The process and pattern of urbanisation in India and abroad has been documented for selected cities by Sovani (1966). Arguing that urbanisation should have followed after sufficient industrialisation, the rapid urbanisation in post-independent and a developing country like India without adequate industrialisation, had caused a situation of 'over-urbanisation' (Sovani, 1966) as early as in the fifties and sixties of the last century. Later on, Rajagopalan (1977) gives a detailed account of the theory of urbanisation addresses the cause-effect relationship between urbanisation and social change. Further discussing the relationship between urbanisation and industrialisation and the feedback between them, Rajagopalan (1977) also notes the concept of 'urbanism'. Rao et al. (1989) study the dynamics of urbanisation based on a 'replacement hypothesis', for which they empirically validate.

In the recent years, the problem and magnitude of urbanisation in India has become evident with several studies being reported. Again most of these studies deal the problem of urbanisation in relation with transportation, energy, land use, vehicular emissions, climate and safety, mostly in isolation. The urban transportation and hence their energy consumption is compared with respect to two urban centres, Mumbai and Bangalore (Sudhakar Reddy, 2000). Significant attempts linking urbanisation with land use change models and transportation are undertaken in the recent years by Srinivasan (2001) and Sudhira et al. (2004) using the cellular automata techniques. In India, several studies addressed urbanisation and urban growth in relation to transportation, energy, land use, climate, etc. but not many studies addressed the problem of urban sprawl until recently (Jothimani, 1997; Lata et al., 2001; Subidhi and Maithani, 2001; Sudhira et al., 2003 & 2004a). Furthermore, there are very few studies on modelling urban sprawl in India (Subudhi and Maithani, 2001; Sudhira et al., 2004b). Similar to trends in research on urban sprawl in advanced countries, the problem of sprawl has been largely addressed in isolation in India. However, the need for integrative approach is now being suggested (Gakenheimer, 2002). Subsequently, as with the studies and definitions on urban sprawl, the metrics and methods to quantify sprawl are still vague. This necessitates arriving at appropriate metrics to address the problem of urban sprawl considering the rates of urbanisation, population densities apart from the spatial extents amassed by urban areas. Subsequently, as with the studies and definitions on urban sprawl, the metrics and methods to quantify sprawl are still vague. It is thus essential for any research while arriving at appropriate metrics to address the problem of urban sprawl in a developing country like India to take into consideration of the rates of urbanisation, population densities apart from the spatial extents amassed by urban areas.

2.5 Metrics and Dynamics of Urban Sprawl: Indicators for Sustainable Urbanisation

Evolving appropriate measures to quantify urban sprawl is a prerequisite to undertake modelling of urban sprawl dynamics. Torrens and Alberti (2000), note that despite the level of importance given to the problem of sprawl, there remains little understanding of its determinants and its constituents, since sprawl is most often confused with sub-urbanisation. However, some researchers in the recent past have attempted to characterise urban sprawl (Barnes et al., 2001; Hurd et al., 2001; Epstein et al., 2002; Sudhira et al., 2004b) using spatial metrics. Essentially, the urban sprawl metrics aids in quantifying the process, monitoring the extent of urban sprawl and also become useful as indicators

for measuring the implications of policy decisions. Although some of the indicators for achieving sustainable development have been evolved by Meadows (1998), still there isn't any broad consensus on the appropriate indices representing all of the factors and disciplines. For managing urban sprawl in north-western European cities, Gayda et al. (2003) have evolved metrics, adopted as indicators to achieve sustainable development. Furthermore, on the lines of sustainable development framework, there also exists quantification of metrics based on the carrying capacity approach. In this case, the carrying capacity of an urban system is evaluated based on the different functions and activities of the urban systems and accordingly a certain threshold for development is set, beyond which it is detrimental to the entire system itself. The concept of carrying capacity has been in news since the seminal work by Meadows et al. (1972), on the notion of 'Limits to growth'. In India, the NIUA (National Institute of Urban Affairs) (1996) has evolved a framework for the carrying capacity based regional planning. The essence of carrying capacity based approach on the lines of achieving sustainable development lies in the fact that a host of factors are under consideration in planning process. Some of the existing works on sprawl ascribe spatial extent of built-up areas derived from remote sensing data or other geospatial data as the measure of sprawl. On the spatial metrics for sprawl, entropy, patchiness and built-up density have been suggested (Yeh and Li, 2001; Sudhira et al. 2004b; Torrens and Alberti 2000). In addition to this, the percentage of population residing over the built-up area to arrive at population-built-up density was considered as metric for sprawl (Gayda et al., 2005; Sudhira et al., 2003). However, it still remains largely unanswered as to how and what are the appropriate metrics or indicators of urban sprawl that are sufficient to represent the process of sprawl. Although some attempts are made to capture sprawl in its spatial dimensions, which fail to capture sprawl process in other dimensions (like, travel times, pollution, resource usage, etc.) and also do not indicate their intensity (density metrics). It is imperative for research to address intensity of sprawl through appropriate metrics or indicators for effective regional planning.

2.6 Approaches to Model the Dynamics of Urban Sprawl

The urban sprawl phenomenon is very dynamic in nature. Although it is often considered endemic, the phenomenon has impacts on the structure and growth of any city or town. Development of suburbs as a consequence of increased population growth and infrastructure facilities around the cities is a well-established reasoning for urban sprawl. Several approaches and methods originating from the disciplines of engineering, management, geography and artificial intelligence have been

used for addressing the modelling of urban systems. Among the key approaches include the System Dynamics framework, operations research methods, geospatial modelling using the tools of GIS and more recently the use of agent-based models in conjunction with geospatial models to capture the dynamics and modelling of urban sprawl.

2.6.1 The Operations Research (OR) Approaches:

A review of different OR methods were done by Catanese (1972). Among the predominantly used methods in OR are probabilistic models, optimisation techniques, linear, non-linear, dynamic, and stochastic programming methods. More recently, the simulation tools are being used extensively to capture and emulate the urban system and its dynamics. These simulations are based on the concepts of discrete-event system simulation approaches. With the emergence of multi-agent systems from the artificial intelligence domain, these are now being used to aid in the simulation of urban systems.

2.6.2 The System Dynamics (SD) Framework:

The SD framework captures the system based on complexity involving dynamic relations represented by the stocks and flows determined by the various activity volumes in the city, which were synthesised from casual knowledge and observation. A key distinction was this model was able to represent the emergent behaviour of the system originating out of complexity.

2.6.3 The Geospatial Modelling:

The origins of GIS date back to late 60s with creation of a spatial database for urban area. Mapping urban sprawl provides a “picture” of where this type of growth is occurring, and helps to identify the environmental and natural resources threatened by such sprawls, and suggests the likely future directions and patterns of sprawling growth. Analysing the sprawl over a period of time will help in understanding the nature and growth of this phenomenon. The tools of GIS and satellite remote sensing data are very useful to study sprawl. The spatial patterns of urban sprawl on temporal scale can be analysed and monitored using the remotely sensed satellite imageries. They can be used in identifying the urban growth pattern from the spatial and temporal data. These help in delineating the growth patterns of urban sprawl such as, the linear growth and radial growth patterns.

3 Modelling and Simulation of Urban Sprawl - Cities as Complex Systems

Modelling the urban sprawl dynamics has closely followed the traditional urban growth modelling approaches, noting the importance and implications of sprawl. Subsequently, with the need to manage urban sprawl, modelling urban sprawl by relating to the nature of growth and its implications has been undertaken since 1960s.

Urban development models were developed much earlier, however modelling dynamics of urban sprawl has been undertaken only recently (Batty et al., 1999; Torrens and Alberti, 2000). The key initial studies in the developed countries on urban growth and urban development models were: Lowry (1967 In: Batty and Torrens, 2001), Walter (1975), Allen and Sanglier (1979), and Pumain et al. (1986). Most of these studies followed the traditional approaches of urban model building. The traditional approach of model building involved linking independent to dependent variables, which were statistically significant, additive as in a linear model or a non-linear model but tractable in a mathematical way. However, these models although used mostly for policy purposes, could not be useful when processes involved rule-based systems, which in practice cannot be tractable mathematical operations (Batty and Torrens, 2001).

Among the path-breaking models developed to capture urban systems, Forrester (1969) attempted to model urban dynamics based on complexity involving dynamic relations represented by stocks and flows which determined the various activity volumes in the city, which were synthesised from knowledge and observation of causal factors. A key distinction of this model was its ability to represent emergent behaviour of the system originating out of complexity. However, this model could not be represented spatially.

Batty et al. (1999) provided spatially aggregate model for the urban sprawl phenomenon. Cheng and Masser (2003) report spatial logistic regression techniques for analysing urban growth pattern, which was applied for a city in China. This study also includes extensive exploratory data analyses considering the causal factors. Later, Sudhira et al. (2004b) attempted modelling urban sprawl in a non-spatial domain.

In an interesting analysis on regional industrialisation in a province in China, Huang and Leung (2002) have employed geographically weighted regression to identify spatial interaction between level of regional industrialisation and various factors affecting industrialisation. It is argued that conventional regression analysis would only produce the 'average' and 'global' parameter estimates which vary over space depending on the respective spatial systems. Thus, they suggest using the geographic weighted regression technique for analysing the spatial non-stationarity of the different factors affecting regional industrialisation.

Furthermore, Allen et al. (1986), Couclelis (1987) and Engelen (1988), clearly acknowledge the self-organisation in urban systems and hence assert modelling urban systems as complex systems. Capturing the urban systems as discrete models gained further momentum with the popularity of the cellular automata (CA) based techniques. Ulam developed CA in the 1940s, and were later used by von Neumann to investigate the logical nature of self-reproducible systems (White and Engelen, 1993; Li and Yeh, 2000) and extensive experiments were done by Wolfram (2002). The most pioneering work in simulating urban growth using CA was done by Couclelis (1987) and Batty and Xie (1994). Now, most models of spatial dynamics rests with land cover and land use change studies (Yang and Lo, 2003) and urban growth models (Batty, 1998; Batty and Xie, 1997; Clarke and Gaydos, 1998; Clarke et al., 1996; Couclelis, 1997; Jianquan and Masser, 2002; White and Engelen, 1993 & 1997) and in urban simulation (Li and Yeh, 2000; Torrens and O'Sullivan, 2001; Torrens, 2000; Waddell, 2002). Urban growth modelling considering the spatial and temporal analyses of land use / land cover changes like LUCAS (Land Use Change Analysis System) model (Berry et al., 1996), GIGALOPOLIS (Clarke et al., 1996), and California Urban Futures (CUF-II) model (Landis and Zhang, 1997). Li and Yeh (2000) develop and demonstrate the constrained CA model for sustainable urban development modelling. Some of these models interact with causal factors driving the sprawl such as the availability of land and proximity to city centres and highway.

CA has been applied for simulating urban growth quite successfully mostly considering various driving forces that are responsible for sprawl. However some of the issues like the impact on ecology, energy, environment and economy for taking policy decisions have not been addressed effectively. To counter the shortcomings of the CA, different approaches are being suggested. Among them is the integration of agent-based models and CA models, as agent-based models can be constructed to capture the externalities driving the processes. Also, with the need for sustainable

development it is essential to integrate the various factors responsible for dynamic process and establish the complex relationships amongst them.

Models developed using CA and agent-based models would prove beneficial to pinpoint where sprawl takes place, which would help in effective visualisation and understanding of the impacts of urban sprawl. Further to achieve an efficient simulation of urban sprawl, modelling has to be attempted in both spatial and non-spatial domain. Modelling urban sprawl in non-spatial domain is mainly by the application of statistical techniques while CA models and agent-based modelling are known to complement modelling in spatial domain. For achieving the integration of CA and agent-based models to simulate urban sprawl phenomenon, Benenson and Torrens (2004) have evolved the Geographic Automata Systems (GAS) framework, while Sudhira et al. (2005) have developed the Dynamic Geo-Spatial Simulation (DGSS) framework.

4 The Integrated Spatial Planning Support System

For effectively managing, testing of different hypothesis, building and visualizing scenarios, it is imperative to have a robust Spatial Planning Support Systems (SPSS) for addressing the problem of urban sprawl. An ideal SPSS would not only aid in managing but also in planning, organizing, coordinating, monitoring and evaluation of the system in question. These systems include instruments relating to geoinformation technology that have been primarily developed to support different aspects of the planning process, including problem diagnosis, data collection, mining and extraction, spatial and temporal analysis, data modelling, visualization and display, scenario-building and projection, plan formulation and evaluation, report preparation, enhanced participation and collaborative decision-making (Geertman and Stillwell, 2004). Such a SPSS for addressing the problem of urban sprawl needs to integrate the different processes associated with the dynamics of sprawl phenomenon. Moreover, a key challenge for technology is to facilitate collaborative decision-making for evaluating different policy options through participatory simulations by different stake holders.

Most of the existing simulation framework allows simulations only on stand alone systems, wherein each stakeholder has to choose/decide the options on same system/platform. This would suggest that all stake holders have to meet physically to evaluate and decide. Moreover such initiatives are not normal and very difficult to moderate. In this context, it becomes necessary for a

distributed simulation framework to support SPSS, so that all stake holders and managers/administrators are able to interact, organise, plan, evaluate and decide through a network. Then the challenges are two fold: one, to integrate different models that are required to carry out the simulations and then, to synchronise the model's inputs, feedbacks and outputs over space and time.

Currently there are few popular frameworks that try to emulate SPSS with an objective to make planning interactive and participatory. Among such existing SPSS are What-If? (Klosterman, 1999), RAMCO (Uljee et al., 1999) etc. What-If? (Klosterman, 1999) is an interactive GIS-based planning support system that responds directly to both achieving the ideals of communicative rationality and traditional comprehensive land use planning. It uses the geographic data sets to support community-based efforts to evaluate the likely implications of alternative public policy choices. The package can be customized to a community's existing geographic data, concerns, and desires, and provides outputs in easy to understand maps and reports which can be used to support community-based collaborative planning efforts. The system requires that given a set of factors and factor weights for determining the suitability, the projections for future land use and subsequently the allocation can be based on the user requirements. Although this system is claimed to be interactive, the dynamics of the factors and hence their interactions are less captured with only a final land use scenario obtained as output and doesn't support a distributed (simulation) framework.

The RAMCO (Rapid Assessment for Management of COastal zones) is a prototype information system in a generic decision support environment for management of coastal zones through the rapid assessment of problems (Uljee et al., 1999). The system is very effective for regional planning that was developed based on the integration of GIS, CA and System Dynamics. Subsequently White and Engelen (2000), the developers of RAMCO, also support the integration of GIS, CA and System Dynamics with the usage of multi-agent systems for an high-resolution integrated modelling of the spatial dynamics of urban and regional systems. This has currently set the standard of technology that can be used for achieving an integrated spatial planning support system. However, this also doesn't support a distributed framework.

Currently there are two other established frameworks and supporting packages for integrated modelling of urban systems, UrbanSim and OBEUS. UrbanSim is implemented as a set of packages under Open Platform for Urban Simulation (OPUS) (Waddell et al., 2005). This is fairly

comprehensive in the sense that framework integrates land-use, transportation, economic, demographics and environment variables but a key draw back is that it is "data hungry". Further, this framework doesn't support participatory simulations. The OBEUS (object-based environment for urban systems) is more robust and emerging trend to integrate various processes as agent-based models to simulate them spatially and hence termed as geosimulation (Benenson and Torrens, 2004). They have also established the concept of geographic automata systems (GAS), to formalize the fusion of agent-based models and cellular automata models in a spatial framework. However, again the key drawback here is that this doesn't support participatory simulations. Although if one may wish to consider each agent-based model as individual simulation model, the OBEUS addresses this using synchronous or asynchronous updating. It may well be a good frame of reference to build a distributed simulation framework for enabling participatory decision-making possible.

5 Challenges

The phenomenon of urban sprawl is potentially observed as a threat for achieving sustainable urbanisation. Hence, it is very essential to understand the phenomenon of urban sprawl especially with the perspective of a developing country. This would eventually aid in evolving any policy and management options for effectively addressing the problem of urban sprawl.

Further, the problem of urban sprawl is observed to be an outcome of improper planning, inadequate policies and lack of good governance due to various reasons. The inability of the planning machinery to visualise probable areas of sprawl and its growth is persistent with the lack of appropriate spatial information and indicators. Added to this, is the inability of the planning and administration to capture the feedbacks arising out different decisions, essentially with lack of dynamic spatial models with feedback mechanisms. Furthermore, inappropriate policy decisions are fuelling sprawl as no mechanism to evaluate for different policy implications, with the lack of spatial planning support systems to test and validate different policy options.

Thus, in the present context, with the escalating problem of the urban sprawl, the challenges for future research is to arrive at an integrated spatial planning support system to effectively plan, review and evaluate the different policy options while capturing the dynamics involved. Such an

SPSS could also be used to regularly monitor and check the nature of sprawl for the compliance of the policy recommendations dynamically over time.

A concluding caveat addressing urban sprawl is that contribution of research by way of spatial planning support system would only be a short-to-medium term solution to this problem. The significant driver of sprawl in developing countries is the migration of people from rural areas aspiring for livelihood to urban areas, which is compounding the problem of sprawl. Hence, a long term solution can only be achieved through an overall economic development of the region by the way of better employment and livelihood generation activities in the rural areas that can lessen the migration of people from rural areas to urban areas and mitigate urban sprawl.

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