URBAN SPRAWL – A SYSTEM DYNAMIC APPROACH

1.0 INTRODUCTION

A human settlement is a living organism. It has origin, growth, decay and, re-growth. It is a dynamic entity, subject to various types of forces, such as, physical, physiological, social, economical, technological, etc. These forces are mainly responsible for rapid pace of urbanisation of human settlement. Urbanisation is a continuous process, which is not merely a concomitant of industrialisation, but a concomitant of the whole gamut of factors underlying the process of economic growth and social change (4).

In this era of globalisation and liberalisation, a phenomenon of urbanisation is distinct reality in developing countries, like, India, China, etc. This rapid pace of urbanisation is posing major opportunities as well as challenges in front of cities in these developing countries. One of the major challenges is Urban Sprawl, which is an inevitable outcome of urbanisation process resulting into various problems in these cities. Attaining Sustainable Development of these cities without Urban Sprawl is a herculean task in front of Urban Planners and Managers; which requires a more scientific and dynamic approach.

An approach taking into consideration an urban area as a whole and the dynamic forces present in and outside it, responsible for its functioning need to be adopted to address this complex issue of Urban Sprawl. In this context, a System Dynamic Approach based on Systems Concept and System Dynamics models seems to be more appropriate which would help the Urban Planners and Managers to meet the challenges of decision-making and policy formulation for sustainable development of Urban System without sprawl. A thorough understanding of System Dynamic Approach is required before its application. Accordingly, a detailed literature review has been carried out by the author and the outcome of the same is presented in nutshell in following subsequent paras.

2.0 SYSTEMS CONCEPT

A system functions as a whole with the interaction of several subsystems. All the sub-systems of the system are interconnected, and interdependent to each other, and form a system. If one of the sub-systems of the system is defunct or functions with higher degree (taking lead role during its function) or partly function, its effects can be visualised in the entire system over a period of time. In some cases, the system may not function at all, while in some cases the system may function, but with many disturbances or smooth functions of the system may be paralysed.

2.1. *System Characteristics*

The various major characteristics of a system as postulated by various Scholars are:

- A system is a complex grouping of human beings and machine.
- A system may be broken down in to sub-systems, the amount of sub-systems detail depending on the problem being studied.
- The outputs from the given sub-system provide the inputs to the other sub-systems. Thus, a given sub-system interacts with the other sub systems and hence cannot be studied in isolation.
- The system being studied will usually form part of a hierarchy of such-systems. The systems at the top are very important and exert considerable influence on the systems lower down.
- To function, a system must have an objective, but this is influenced by the wider system of which it forms a part. Usually, systems have multiple objectives, which are

in conflict with one another, so that an overall objective is required which affects a compromise between these conflicting objectives.

- To function at maximum efficiency, a system must be designed in such a way that it is capable of achieving its overall objective in the best possible ways.

Thus, all living systems maintain steady state dynamic equilibrium keeping an orderly balance among its sub-systems with respect to its super system and the environment. However, if an element of a system fails to handle a stress, other elements come forward and share this excess stress.

2.2. *Systems Theory*

Various forms of systems theories have been proposed over the years. The important ones among them are General System's theory, Cybernetics, Systems Approach, and System Dynamics approach.

General System theory has its genesis in the original research of Ludwig Von Bertalanffy on study of biological organism (1920s and 1930s) and theory of open systems (11, 10), which was both supported and criticised by many Scholars (1,5,41). The broad objectives of the theory (13) are to investigate the isomorphic of concepts, laws and models in various fields and to help in useful transfers from one field to another, to encourage the development of adequate theoretical models in areas which lack them, to eliminate the duplication of theoretical efforts in different fields and to promote the unity of science through improving communication between specialists. However, this theory has not properly emerged due to lack of methods capable of implementing it.

Cybernetics is proclaimed to be a theory of communication and control in animals, society, and machines (5, 9, 8, 51, 52). The elements of the theory are feedback, self-regulation, control, and information transmission. It uses the concept of entropy in communication theory and uses this as a measure of disorder, uncertainty or variety of systems. This theory has inspired to analyse the problems arise in social systems; however remain largely verbal, and often graphical rather than mathematical.

Systems Theory is an outgrowth of the concepts of General Systems Theory and cybernetics. It is more of a practical philosophy of solving problems in societal systems. It suggests a holistic approach in defining the problem, defining the objectives of the system, designing the change, and evaluating the design and known as design methodology (26). The characteristics of this theory are:

- The problem of a system is defined in relation to super-ordinate systems to which a community of objectives relates it.
- The objectives of the system must be viewed in relation to these super-ordinate systems or the whole system.
- Present design must be evaluated in terms of opportunity costs or the extent of divergence of the system from the optimum design.
- The optimum design cannot usually be found incrementally nearby present adopted forms. It involves planning, evaluation, and implementation of new alternatives, which offer innovative and creative departures from the whole system.
- System design involves processes of thinking, such as, induction and synthesis, which differ from deductive and reductive methods used in the scientific method of system improvement.
- Planning is conceived as a process where Planner assumes the role of a leader rather than that of a follower, so those problems are prevented from occurring rather than solved when they occur.

- It is universally accepted that it is one of the most potent ways of undertaking a systematic inquiry. However, it does not recommend any specific methodology, which guides the actual employment of approach.

The System Dynamics approach amalgamates ideas developed in various System Theories and is a result of cross-fertilisation of ideas from traditional management, cybernetics, and computer simulation. It is a theory of structure and behaviour system (22). It presents a very easy to use intuitively appealing and yet use mathematically sophisticated methodologies while undertaking practical systems enquiry. Moreover, System Dynamics has its genesis to Industrial Dynamics, where it is said to be the study of information and feedback characterisation of industrial enterprises to show the interaction of structure, amplification and time delay to influence successes of an enterprise (21), and is adopted for investigating dynamic behaviour of feedback systems (21, 27). It is applicable to other complex social systems other than industrial systems with problems of controllability (15), such as, urban systems (12, 13, 19, 53, 25, 28, 32, 33, 36, 34, 35, 39, 44), world systems (19, 53), tourism systems (31, 42, 43), which deal with socio-economic systems and management.

The theory has its inherent weaknesses and criticised for the limitations such as, Scarce data were used to build models, models were highly aggregated, absence of quantitative validity, practice of trial and error during policy design, methods of judging parameters sensitivity of models, etc. However, after a number of improvements, over the years System Dynamics has emerged as one of the most powerful methodologies of social systems analysis and design at aggregate level for its ability to address itself to very important long term and short term issues of real system, its ability and simplicity to model complex, non linear relationships, its ability to model soft social and psychological variables, the ease with which the effects of alternative policy options can be tested, and the ease in communicating the model, the results and recommendations (42).

2.3. *Application of System Dynamics Theory*

System Dynamics Theory has been employed to a wide range of problem domains. It includes works in corporate planning and policy design (21, 38) economic behaviour (46), public management and policy (69), biological and medical modelling (29), energy and environment (47), theory development in the natural and social sciences (16), dynamic decision modelling (48), complex non-linear dynamics (47), software engineering (1), supply chain management (2,7, 49), tourism system dynamic model (31), and integrated tourism dynamic model (43).

3.0. SYSTEM DYNAMIC MODELLING

System Dynamic modelling is one approach that can help the Urban Planners and Managers to meet the challenges of decision-making and policy formulation for the development of a system. It represents the key feedback structures in the system. Simulating the model shows the effect of the system structures on policy interventions. It is a problem evaluation approach based on the premise that the structure of a system, that is the way essential components are connected, generates its behaviour (40, 47). It is well suited to analysis of problems whose behaviour is governed by feedback relationships, has a long-term time horizon (50), and not suited to one-time decisions. The process of creating a simulation model helps clarify the resource management problem and makes modeller assumptions about the way the system works explicitly. The most important advantage of this model is once the model is built; it can be used to simulate the effect of proposed actions on the problem and the system as a whole. In this regard, Forrester (1987) noted that this kind of tool is necessary because, while people are good at observing the local structure of the system, they are not good at predicting how the complex and interdependent the system will behave (20).

System Dynamics proceeds through several major steps (17, 40) and these are the same steps followed in any problem solving process. This is also an iterative process and results at any stage can feed back to previous steps. The various steps for developing and employing the System Dynamic models are:

- Define the problem
- Describe the system
- Develop the model
- Build confidence in the model (Validation)
- Use the model for policy analysis
- Use the model for public outreach.

Building a model for decision support within an organisation may use only first five steps and using the model for public communication includes the next one.

3.1. *Define the Problem*

The first step in System Dynamic modelling is to identify the key variable whose behaviour over time defines the problem. The consequence of a system of interactions among large numbers of variables needs study through modelling to recognise a problem. The interactions of these variables operate on feedback mechanisms and generate the dynamics of the system. In the identification stage, it is important to interpret the problems and the causes thereof from the past behaviour of the system. In a social complex system, it is difficult to build a reference mode and identify a problem. In such situations, the problem is identified through discussions with experts, interviews, questionnaire surveys, Delphi, etc., study for building up a rich picture of the situation and record multiple perspectives for a problem situation looking at the interactions from different angles (13,37).

3.2. *Describe the System*

Describing the system involves identifying the system structure that appears to be generating problematic trend. This entails extracting the essential elements and connections from the real system that produces the anticipated or observed behaviour. At this stage, fixing model aggregate and boundary is of paramount importance and should be free from any mental fixate or obsession. All the factors relevant to the description of the problem phenomena under investigation are to be included, therefore a large number of variables those influence the system are brought within the system boundary for comprehensiveness. The final representation of important variables and causal links called dynamic hypothesis, which is the system structure, is thought to explain the dynamic behaviour of the system.

3.4. *Develop the Model*

A detailed model is developed based on the dynamic hypothesis, by representing through flow diagrams, which takes into account the physical resources and information linkages at the time of their construction. Further, the variables are presented in different forms to identify them as Stocks or Levels (accumulation), Rates (decisions), Auxiliaries (algebraic subdivision of rates) or Converters and parameters. Model assumptions are also incorporated while developing the model.

3.5. *Model Validation*

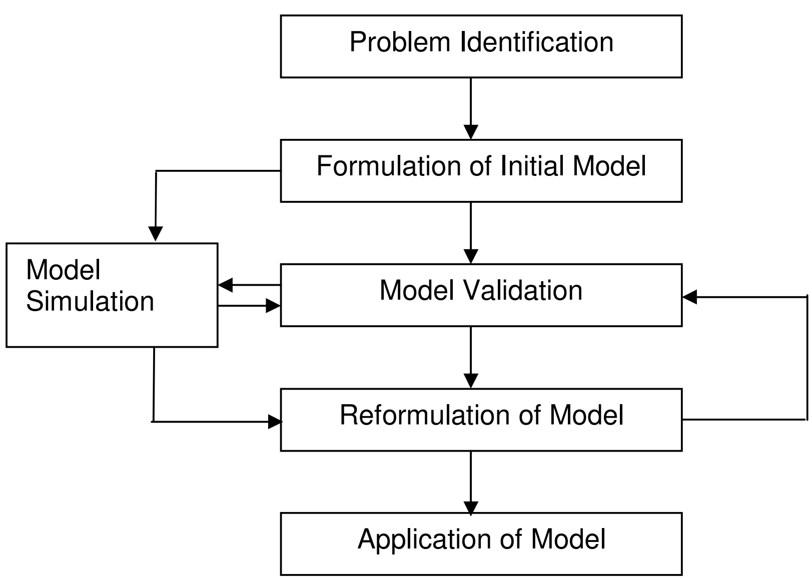
In System Dynamic modelling, the ultimate objective of the validation process is to establish the structural validity of the model with respect to the modelling purpose. It is critical because the purpose of a system dynamic study is to evaluate alternative strategies, or policies to improve the behaviour. Accuracy of the model behaviour is meaningful only if there is sufficient confidence in the structure of the model. Validation needs to be applied at every stage of modelling. It is required to be validated against the observed or anticipated trend (22, 33, 36, 34, 35, 42) and sometimes individual tests, such as, structure oriented behaviour tests (6, 24), extreme condition, behaviour sensitivity and phase relationship tests (6) are used for detection structural flaws in the model. If the model reproduces the trend and represents the real system as it actually works, then the model leads to accurate behaviour or else the second step must be revisited to revise the dynamic hypothesis or model structure.

3.6. *Use the Model for Policy Analysis*

When the model is validated, it can be used to test the effects of policy interventions on the problem. It includes studying the model structure to identify policy levers, then simulating the effect of those changes. The effects of policies can be analysed both quantitatively and qualitatively. In the qualitative approach, the evaluation primarily predicts the effect, which improves or worsens the system behaviour, while in quantitative approach the evaluation is rigorous and uses precise numerical values.

3.7. *Use the Model for Public Out-Reach*

The model has the ability to involve the stakeholders, to make the models more effective for policies decisions (3, 14, 45, 50). Even when stakeholders are not involved in the model development process, a completed model can be an effective public outreach too. The schematic diagram developed by Hamilton, et al. (1969) is presented in Fig. 1 showing the steps the model used for evolving in System Dynamic modelling (28).



Source: Hamilton, et. al., 1969

Fig. No. 1: Model Development as an Iterative Process

4.0. INTEGRATED URBAN SYSTEM MODEL

The Urban Area is considered as a system, and it has several subsystems. The various subsystems of the Urban System are physical, social, economic, ecological, environmental, infrastructure, institution, etc. All these sub-systems are interlinked and interdependent to each other and function as a whole dynamically. The dynamic functions of the urban system along with its different subsystems are presented in Fig. 2.

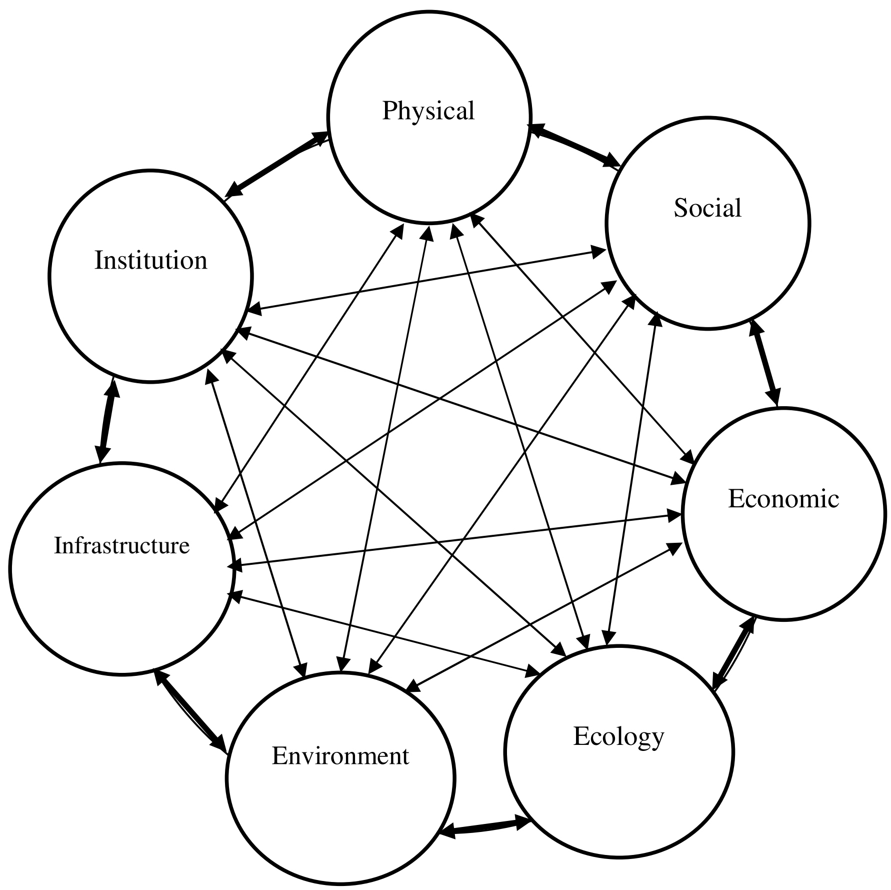


Fig. No. 2: Functions of the Urban System along with its sub systems.

5.0. CONCEPTUALISATION OF SYSTEM WITHOUT URBAN SPRAWL

In this paper, the Urban Area is considered as a System, integrating physical, social, economic, ecological, environmental, infrastructure and institutional subsystems; where Urban Sprawl is an outcome of change in performance / functioning of these subsystems. The discussion with experts and survey conducted to identify the problems of the system while conceptualising model revealed that there are mainly three controlling parameters, such as, Population, Connectivity, and Functions responsible for the Urban Sprawl in the System as represented in Fig. 3 and are discussed in detail below in subsequent paras.

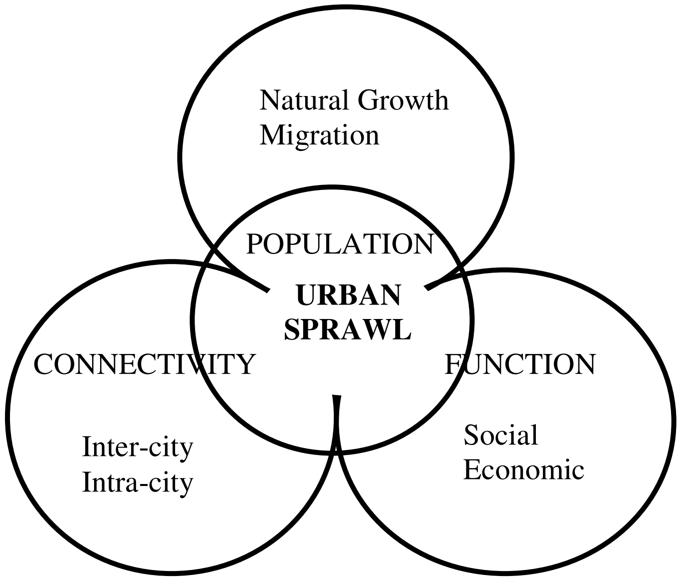


Fig. No. 3: Parameters Responsible for Urban Sprawl in the System.

5.1. Population

Population acts as a basis for existence of any Urban System. Any change in population directly affects performance of the Urban System. Increase in population on account of natural growth, i.e., difference between birth rate and death rate as well as migration, i.e., difference between in-migration & out-migration rate leads to variation in the performance of the Urban System and grounds to Urban Sprawl if not handle properly.

5.2. Connectivity

Connectivity provides vital link to interlink human activities in tangible and intangible forms in and outside of the Urban System. Any change in connectivity at the level of inter-city and intra-city on account of economic prosperity coupled with technological advancement leads to the dispersal / re-organisation of population and functions in and outside of the Urban Systems and grounds to Urban Sprawl if not handle properly.

5.3. Functions

Functions acts as one of the most important dynamic entity in the Urban System, comprising of various types of functions, such as, Social, Economic, etc. Any change in the functions, in terms of scale or any addition-alteration in them directly affects the performance of the Urban System by attracting more population leading to Urban Sprawl if not handle properly.

Performance of these parameters, which are interdependent, at the individual level or combined together leads to change in overall performance / functioning of the Urban System and resulting into Urban Sprawl; if the same is not addressed properly. Therefore, to evolve polices and plausible guidelines for the sustainable development of System without Urban Sprawl need to take into account all these important controlling parameters.

6.0. CONCLUSION

A detailed study of System Dynamic Approach based on Systems Concept and System Dynamics models revealed that complex issue of Urban Sprawl would be addressed properly by evolving policies and plausible guidelines. System Dynamic Model would be developed based on the survey data and historical data, by taking into account major controlling parameter, such as, Population, Functions, Connectivity, etc. responsible for Sprawl in the Urban System. Model simulation would be used to understand the influence of these important controlling parameters on the overall functioning / performance of the Urban System and to arrive at optimal policies and plausible guidelines for sustainable development of Urban System without sprawl.

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