Review of Simulation Techniques Used To Predict Urban Development

Abdul Azadh Abdul Saleem  
M.Sc. in Data Analytics *National College of Ireland   
Dublin, Ireland*  
x18203621@student.ncirl.ie

*Abstract*— This report investigates about the different techniques used for developing a simulation model of the dynamics of urban development in the major cities, in the past decades. The first paper discussed in this report was published in 1981, which explore the dynamic model that analyze the self-organizing aspect of the evolution of the land, discussed along with possible outcomes of such evolution. From the early years of 1990s decade until in recent years, the technique of Cellular Automata (CA) had been widely used for the developing the simulation models of Urbanization. The paper established in 1998, describes about the utilization of CA for simulating the urban land development in southern Chinese city, along with multicriteria evaluation method (MCE) which helps to define the transition rules for the simulation of the land development. The paper published in 2002, proposed the utilization of neural network for defining the transition rules for the Cellular Automata simulation of urbanization, because of its advantage of adapting the transition rule depending on the changes in the simulation environment. The article published in 2013 has proposed the hybrid simulation model for urbanization using Logistic Regression, Markov Chain and Cellular Automata models. This report will critically review the journals and reports the observations of the techniques used for simulation.

Keywords – Simulation, Urbanization, Decision making, Cellular Automata.

# Introduction

Simulation is the process of creating the scenarios that could occur in the real-time environment, which could help the researcher to study the upcoming outcome of any particular process before even it occurs. This process has eventually acquired its importance in different fields where the scenarios must be simulated under certain circumstances in order to study the impact of certain factors. Various field like Medical research, Development planning, Space Research, Industrialization, etc. have adopted this technique in order to study the different behavior or pattern of development of their subjects considered.

The process of simulation plays a vital role in urban development with the help of its advantage of simulating the problems that could arise due to unintended driving factors of development and the mitigate the factors while designing the development plan of the urban city. Problems like water scarcity, insufficient transportation, over concentration of population on a particular places and many other issues can be simulated and this computed environment provides the researcher the ability to test their remedial measures for such problems and their outcomes, even before they occur in real-time. This method is cost-effective that it helps the researchers to understand the nature of the growth pattern and the decisionmaking ability in the simulation helps to evaluate the performance of the model with alternate decisionmaking transition rules.

The report investigates the simulation techniques utilized in the past four decades of the urban development field. From the beginning of the 1990s-decade Cellular Automata model, which can simulate the probabilistic change of different landscapes with the help of observation from the pattern of the change in land in the historical data of that region. However, the behavior of the change pattern must be controlled by providing the rules for transition which considers the factors that constraints or enables the growth pattern of the region. The method of defining this transition rules has evolved over the decades which has been reported in the document.

# Literature Review

1. *Urban evolution, self-organization and decisionmaking, 1981.*

This paper [1] describes about the simulation of the probabilistic urban development in the region of Bastogne in Belgium. The factors of employability, number of available jobs at particular region, availability of the market and number of residents were considered in this research which helped to develop the simulation model of the urban sprawl. There were four different equation derived, considering the different factors of development, which could help in the developing the growth pattern of the simulation. The dynamic equations are derived to analyze the possible outcomes experiment at any instance of the simulation. For the purpose of simulating the urban development, the data about the evolution of the urban development in Bastogne region between 1947 to 1971 has been utilized for this research.

#### Simulation

The simulation of the urban development of the region has been developed considering the areas of industrial establishment as the points with higher functional values around which the population growth occurs depending the various factors considered in deriving the dynamic equation. The points of the simulation are observed to be sequence of establish of population around the point considered with higher values and the simulation is tested at different instance of time. And it has been observed that some point with higher functional values initially started to lose the population due to the negative feedback factors of inadequate space in the region and establishment of small entrepreneurs.

#### Alternate Decisionmaking

The simulation had been done with the help of considering the driving factors and observation has been done. As a part of alternative decision making, certain procedures were done as mentioned below,

* Considering the population of the particular region to be unchanged for successive periods of time, which is called as Polarization of region.
* Providing the stimulating factors like development of roadways to the suburban (Underdeveloped) areas which could enable the increase in the population of that areas.
* Placing an investment in the area which is less populated by increasing the functional value of particular point in the simulation which could lead to the change in the simulation pattern of the urban development.

To discuss about the advantage and disadvantage of this research, this research has considered the possible outcomes of the self-organization of the individual population, provided which different function values which could help the individuals of the population to behave independently. And the outcome of the simulation had been evaluated with the possible influencing factors which could help the researcher to provide the insight of the alternative outcomes of the simulation. This proposed model has the disadvantage of not considering the human factor which makes the individual point to act individually and make considerable difference in the development of urban population. In addition to the above the research had excluded the factors such as political influence and other factors which are not considered for development of urban region.

This approach is more of theoretical than effective practical application, which has been overcome in the below paper.

1. *Simulation of land development through the integration of cellular automata and multicriteria evaluation, 1998.*

This paper [2] published in 1998, utilized the technique of Cellular Automata (CA) for developing the simulation of the urban development and utilized the multicriteria evaluation (MCE) approach which helps in decisionmaking of the growth simulation of the urban development. As the factors of decisionmaking this research has considered the factors like the preference of the urban developers, transportation nodes in the region and other local factors.

Through this method of decisionmaking the advantage of defining the decision-making parameter can be achieved, which is better than being systematically adjusting the transition rules of the simulation model as mentioned in the previous paper. Additionally, the simulations developed can also be tested for the several hypotheses which have been considered for the research.

This MCE-CA framework provide the user the advantage of usage of multiuse scenario in which allow it to allow to simulate and evaluate various scenarios considering different factors of consideration. When the factors causing the development were correctly defined, then the simulation developed from the model will provide the discriminative difference in the development pattern of the urban population.

The author has defined the equation for the simulation of the urban development by considering the state of land use at different time instances, situation of development influenced by the neighborhood factors and the transition rules defined. The size of kernel defines the size of the cell that captures the characteristics of the landscape. The interaction of the development pattern in the historical data has been captured by adjusting the size of kernel (i.e. is 3\*3 pixels here), which provides the information of proportion of different landscapes in the eight neighboring cells around it at time (t), which was collected as the dynamic local values that are grouped to get the global value. This global value will help the simulation model to define the state of the particular cell at time (t+1).

The advantage of integrating the MCE-CA technique to simulate the future growth of the urban development is the process identifies the factors that could help in development of the land, after which the weights were defined to the points depending on the hierarchy of the landscape by the process of Analytical Hierarchy Process (AHP), which could help the model to define the state of the particular cell at the time (t+1). The hierarchy chosen here is descending, where the weights decrease down as the criteria of the land decreases, and it was argued that this method reflects the real-time scenario of the land development. But the different combinations of the considering parameter values may lead to completely different simulation of the land than actual data of the land for that instance.

This simulation method has the disadvantage of not disclosing the individual weights and the resulting outcome at the time (t+1). This technique has the ability to generate the simulation of the binary values of target land development (i.e. urban land or no) by providing the development factors to influence the growth pattern whereas when it comes to simulate the growth pattern of multiple landscape pattern this method fails, thus this disadvantage can be rectified by employing the neural network based cellular automata method for generating the simulation for more than one land change pattern.

1. *Neural network-based cellular automata for simulating multiple land use changes using GIS, 2002.*

This article [3] published in 2002 had proposed new technique of employing the deep learning based simulation of multiple landscape change with the information acquired from Geo-information system. In this technique multiple layers of neural network were proposed that can calculate the multiple probabilities of conversion of landscapes through repetitive iterations of networks in loop. This model has the advantage of automatically generating the parameters of the simulation which could control the development of the growth of the cells representing the particular landscape. During the series of continuous development there any many new features that appears in the iterations of the land use data which are not captured as the driving factors of the simulation, but this method overcomes such issue by considering the new parameters as the factors that influence the future development of the simulation.

Neural network provides the advantage of considering ‘N’ number of land use classes which can generate the ‘N x N’ number of possible conversions of the land, which makes this model suitable for simulating even the complex relationship of the land classes because of its ability to map the non-linear factors as well. Neural network proposed in this research consist of three layers input layer, hidden layer, and the output layers. The multiple landscapes of the considered data had been loaded in the input layers which then proceeds to the hidden layer where the network tries to learn the pattern of the different land classes through multiple iterations. This methods has the ability to back propagate the function value attained at the end of each loop which could help the network to learn the errors occurring in the every iteration of the parameters and gradually decrease the error in successive iterations of the learning process. By this method of multiple learning of the class of landscapes the resulting output layers has the probabilistic conversion capability values of every individual land class which extends between 0 and 1. And this output value is then provided as the parameters to control the simulation of land conversion of Cellular Automata model.

This method has the limitation such as the less ability to quantify the land development of the simulations. Moreover the neural network method need more temporal data of the considered landscape in order understand the pattern of the change in the landscape, and providing the less data will ultimately lead to producing the irrelevant parameter values which could lead to wrong simulation of the landscape. And the process of neural network is not disclosed which makes the researcher or the users to have less knowledge about the background process of land conversion occurring in the simulation. This issue has been addressed in the paper proposed below where the researcher has proposed the methodology of using the hybrid model for developing the simulation of the multiple landscape for the future prediction.

1. *Integration of logistic regression, Markov chain and cellular automata models to simulate urban expansion, 2012.*

In the article [4] published in 2013, the author has proposed the new hybrid model of integrating the logistic regression, markov chain and cellular automata model for simulating the land use and land cover of the particular area in the future. This method provides the advantage of enabling the researcher to get the information about the quantity of the land change occurring in each simulation, with the help of Markov chain technique. The model also enables the researcher to understand the process of the land change occurring in the simulation model at each step and can evaluate the simulation at each step of the process.

Logistic Regression is the method which has the ability to observe the empirical relationship between the driving factors and the urban land development occurrence in the considered land space. The sampling of the population of the dispersion of landscape factors can occur in two different ways i.e. systematic sampling of the data and random sampling of the data but both has the issue of decreasing the spatial dependencies in the data, which has been overcome by integrating the method with cellular automata model. Markov Chain model integrated in this approach provides the probability of the change in the cells of the simulation matrix with the help of transition probability matrix. Markov model defines the state of change of land classes in the future with the help of limited temporal data of the region over time and observing their change pattern. Cellular Automata model has the ability to observe the spatial information of the region of the data over different period and consider them as the influencing factor for the simulating the future development of the landscape. Integrating these three techniques into one hybrid model makes this approach more robust than the other models developed before and the quantification of the change can be calculated with the help of transition probability matrix of the area which provides the frequency of land change over time which helps to calculate the transition area matrix which provides the information of quantity of the pixels that has the ability to change its state to any other land class in the future simulation. The quantified pixel with the probability of changing the state will help in calculating the quantification of landscape change at different instance of time.

Despite of all its advantages this proposed technique still has the disadvantage of not considering the human factor and actions of the government bodies in the development of urban lands.

# Conclusion

Simulation of the urban development of major cities has been a popular process for understand the future growth pattern of urban sprawl in the region. Thus, from the review of the papers from the past decades has provided the insight about the evolution of such simulation model employed to understand the urbanization. The simulation model discussed in the 1980s decade is more of theoretical based, where the successive decades have started utilizing the technique of Cellular Automata which is more providing the real-time simulation of the urban development. The papers discussed from the other decades has information about the developed methods of providing the parameters as transition rules to the simulation model which helps model to perform better than the previous model. However, all these implementations have not considered the factor individual human reaction to the change and emotional factors which provides the change of deviating the simulation from the actual output.

# Reference

[1] P. M. Allen and M. Sanglier, “Urban evolution, self-organization, and decision making.,” *Environ. Plan. A*, vol. 13, no. 2, pp. 167–183, 1981, doi: 10.1068/a130167.

[2] F. Wu and C. J. Webster, “Simulation of land development through the integration of cellular automata and multicriteria evaluation,” *Environ. Plan. B Plan. Des.*, vol. 25, no. 1, pp. 103–126, 1998, doi: 10.1068/b250103.

[3] X. Li and A. G. O. Yeh, “Neural-network-based cellular automata for simulating multiple land use changes using GIS,” *Int. J. Geogr. Inf. Sci.*, vol. 16, no. 4, pp. 323–343, 2002, doi: 10.1080/13658810210137004.

[4] J. J. Arsanjani, M. Helbich, W. Kainz, and A. D. Boloorani, “Integration of logistic regression, Markov chain and cellular automata models to simulate urban expansion,” *Int. J. Appl. Earth Obs. Geoinf.*, vol. 21, no. 1, pp. 265–275, Apr. 2012, doi: 10.1016/j.jag.2011.12.014.