Urban Area Development in Stochastic Cellular Automata

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Abstract

Urban is still an interesting topic to discuss whether in government or public studies. As economy grows in cities, many people are attracted to come to cities from villages to try their luck. In this paper, we investigated urban area development using von Thunen's economic location theory. By using stochastic Cellular Automata which views land location as agents that will change their states in agriculture, industry, and service series, here we show how the urban areas dominated by economy, industry, and service activities develop to their surroundings and form areas with typical activities with urban area. Even for the farther agriculture area from urban center, von Thunen's theory is still valid.

Keywords: von Thunen's Theory, urban, Stochastic Cellular Automata, Markov matrices

1.1 Introduction

Urban is still an interesting topic to discuss whether in government or public studies. As economy grows in cities, more people are coming there to try to find their luck. According to Pitirim Sorikin (1959), many people wanted to improve their social class hoping to vertical mobility, so they came to cities. Instead of vertical mobility, most of them only receive horizontal mobility (e.g., farmer becomes labor). Of course, the rapid growth of people coming to cities becomes a problem especially to government deciding policies.

Government tries to make some policies to regulate the number of urbanization. Some make the city as a closed city which means no one can enter the city, like in Jakarta when Ali Sadikin was a governor. Besides making city as a closed city, there are also some policies to make satellite cities (suburb) such as Ciputat, Bintaro, Bekasi. Although the making of satellite cities mobilize people from city for housing but there are other problems rising, i.e.: transportation and traffic jam. We see nowadays there are a lot of new flyovers being built but still cannot answer the traffic jam problem. The city government also has to opt with the problem of land use whether to build new settlement for urban poor, build new shopping malls, build new houses, or else. These are the problems that the city government has to concern with.

1.2 Several Definitions

To give limitation on our paper, we want to propose some definitions, they are:

a) **Urbanization** is redistribution from the countryside to the city. According to that, urbanization is measured as numbers of population who reside in urban area.
b) **Urban Structure** is an arrangement of urban area (Wikipedia). In this paper we use von Thunen's.
c) **Suburbs** are inhabited districts located either on the outer rim of a city or outside the official limits of a city (the term varies from country to country), or the outer elements of a conurbaniton.

1.3 Previous Works

The urban problem has played great attention for centuries; so here we would like to consider some previous works.

1. John Heinrich von Thunen's works gave a predictive model of rural development around an idealized isolated urban center, imposing several simplifications in an attempt to focus on some of the fundamental processes at work in settlement patterns and rural economic activity. It is presently a regular component of introductory economic geography courses. Despite criticism for oversimplifications, it has persisted in geographic, economic, and rural development curricula.

   His founding was meant as generalization towards discovering laws which govern agricultural prices and translate them into land use patterns. (Yuya Sasaka & Paul Box, 2003).

   He also considered four generalized types of economic and agricultural activities.

2. **Yuya Sasaki and Paul Box (2003)**

   Yuya Sasaki and Paul Box developed a model to demonstrate whether a collection of autonomous individuals can contribute to the formation of this optimal pattern, without any system-level optimization capabilities. They also analyzed the mechanism that leads to an emergent spatial optimization by applying theories of positive feedbacks and lock-in. They used agent-based modeling with cellular automata, and the software called SWARM.

2. Model

We develop von Thunen's location theory using stochastic cellular automata approach to model the emergence of urbanization and the change of the urbanization.

Von Thunen's location theory divided economic location structure into four types of agricultural activities that surrounded a city. Each of them will form a ring that scopes an area through another, visualized in figure 1.

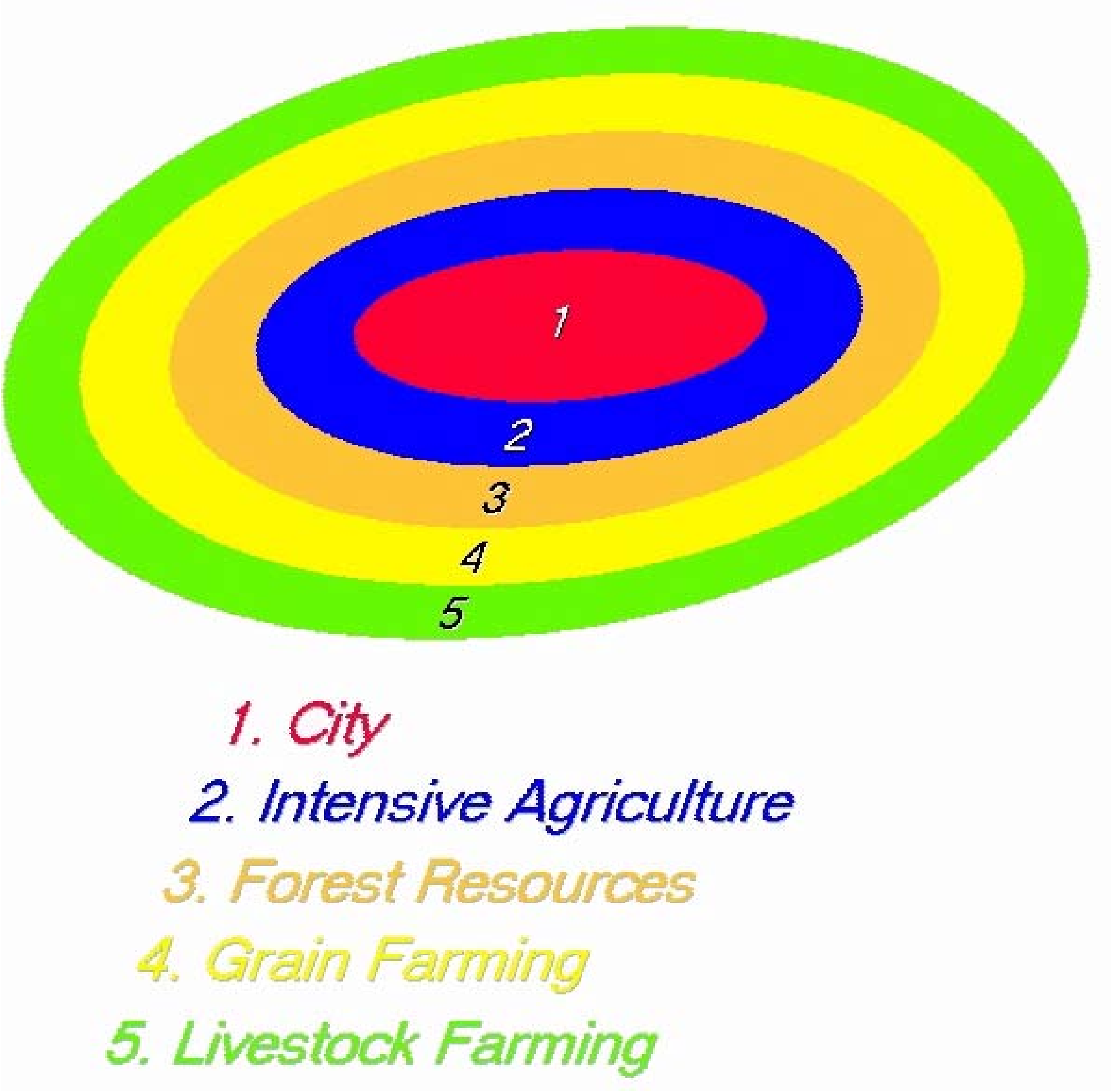
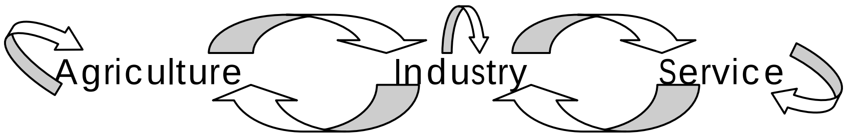


Figure 1 Von Thünen's isolated state (source: JASSS)

In this paper, we made four other agricultural activities types in one type, which is non-urban; hence von Thunen's location model becomes a city surrounded by non-urban area. Generally, economic activities in a city which are high and dynamic will attract people from non-urban area; hence it makes a city as an urban area directly. Furthermore, besides using that assumption, we take a closer look at economic area divided from von Thunen's location area, especially in city area and non-urban area (four agricultural activities types). The result of that, von Thunen's location model becomes:



We divide into these categories based on assumption that a city area will become a center of economic service; suburban becomes economic industrial area; and village become economic agricultural area. We tried to simulate how the emergence appears in the suburban area and its change. As time goes by, numbers of people in city area will increase until reaching city space's limit to push to shift some of economic activities to the outer city area, including settlement problem.

While in village area in which economic agricultural activities has some kind of superiority compared to city in this case more space availability, this difference will become an important factor in relationship of city and village. The city needs more space to fulfill economic activities and the other sides; village needs high economic activities to support its economic activities, instead of the increasing numbers of population in each side which demand more spaces and appropriate economic activities (availability of job fields).

We limit factor which pushes the change of land-use function in this model only to economic problem. Land-use function in location is symbolized as a cell which has location $i, j = 1,...,N$ and in an area $k, l = 1,...,M$ in this paper M = 3 (agriculture, industry, service). At each specific time there is impossible for two different land-use functions.

$$N_i^k(t) = 1, N_i^l(t) = 0, k \neq l, l = 1,...,M, \sum_l N_l^k(t) = 1$$

Aggregately, all cells being in area l aredefined as:

$$N^k(t) = \sum_i N_i^k(t)$$

Meanwhile in total all cells being in all areas are

$$N(t) = \sum_k N^k(t)$$

The change of state from area k to l in time from t to t+1 defined as:

$$\Delta N_i^{kl} = 1, N_i^k(t) = 1, N_i^l(t+1) = 1$$

And sum of total cells which migrate from area k to l is:

$$\Delta N^{kl} = \sum_i \Delta N_i^{kl}$$

Hence total cells which choose area l in time t+1 are:

$$N^l(t+1) = \sum_k \Delta N^{kl}$$

Can be written as probability change:

$$N^l(t+1) = \sum_k P^{kl} N^k(t)$$

With:

$$P^{kl} = \frac{\Delta N^{kl}}{N^k(t)}$$

Equation above is explained as a change probability area from k to l globally, but how does probability change area from k to l at cell i? Claudia Maria de Almaida et al [Almaida, C. M. (2002)] proposed general equation, i.e.:

$$p_i^{kl}(t) = \Theta[f(X_i^1, ..., X_i^E), g(N_i^k(t), N_j^l \in \Omega_i, l \in M)]$$

First element from function Θ, is f(.) explain factors influenced cells in some different area state meanwhile function g(.) describes neighbors influenced from cell i, especially the equation can be defined as:

$$p_i^{kl}(t+1) = \Psi\left[\frac{P^{kl}(t+1)}{1 - P^{kl}(t+1)}\right] \exp \sum_e \tilde{W}_{ie}$$

With $\widetilde{W}_{ie}$, describes weight to measure whether relevant or not a factor to change from k to l in cell i meanwhile Ψ is a normalized constant to probability function. If neighbor element is considered as a factor influenced to cell i in taking decision, thus:

$$\hat{p}_i^{kl}(t+1) = \gamma \left[\frac{\sum_{j\in\Omega_i} N_j^i(t)}{4} \right] p_i^{kl}(t+1)$$

Equation above is trying to connect between cells behavior to the global condition which in this model assumed neighbors from each cell is 4.

3. Simulation and Numerical Analysis

In the next simulation, we involved three conditions in an area, i.e.: agriculture, industry, and service. Each area location in one specific time is only representative one from conditions above. But change dynamic between conditions, which explain change probability area state becomes another area approach with Markov matrices, which is:

$$P = \begin{pmatrix} .85 & .15 & .5 \\ 0 & .80 & .2 \\ 0 & 0 & 1 \end{pmatrix}$$

From left to right (column) or from top to bottom (row), each of them explain change probability from state of agricultural area, industrial area, and service. In practice, Markov matrices above can be resulted through comparing change area state in previous years. Also, we may see that Markov matrices above are government policy to arrange its area. In this simulation, matrices above are used as a constant unit, although this can be extended as a function of time.

Next are simple steps for simulation in this paper (World X size x World Y Size: 100 x 100):

1. In initial stage, area is divided into agriculture, industry, and service. The difference between urban and non-urban area is laid in percentage from that each state, also each land location has economic weight factor, $\widetilde{W}_{ie}$ in this simulation it is a function of distance from urban center. This condition is an initial condition in simulation stage.

2. Each location from land will have state change or don't have push from Markov matrices. This change caused by Markov matrices is global push which will be accepted by an agent as external pusher while to change itself influenced by environment around, in this term its neighbors' decision.
3. Each land location will receive influence from its neighbors based on the number of probability neighbors' value to stay in its state.
4. The result from 2 and 3 will decide land state whether change or not.
5. This process is iterated from procedure 2. and so on

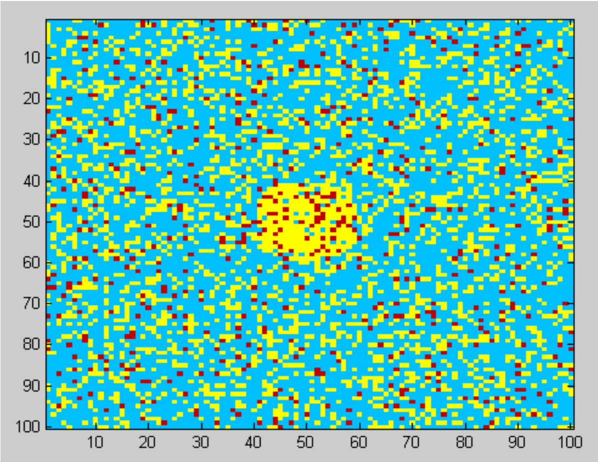


Figure 2

Initial condition (t=0), in center is urban area dominated economic activities in industries (yellow) and services (red). Meanwhile in non-urban area is dominated by agricultures (blue)

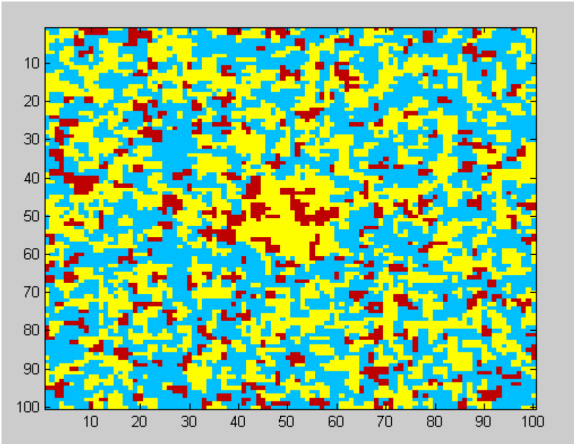


Figure 3

This is 5th iteration from initial condition in Figure 2, shows that it is start to change of land state, in urban area is increasing in economic services and this increasing is still higher than in land for industry. While it is also happens in outer urban area.

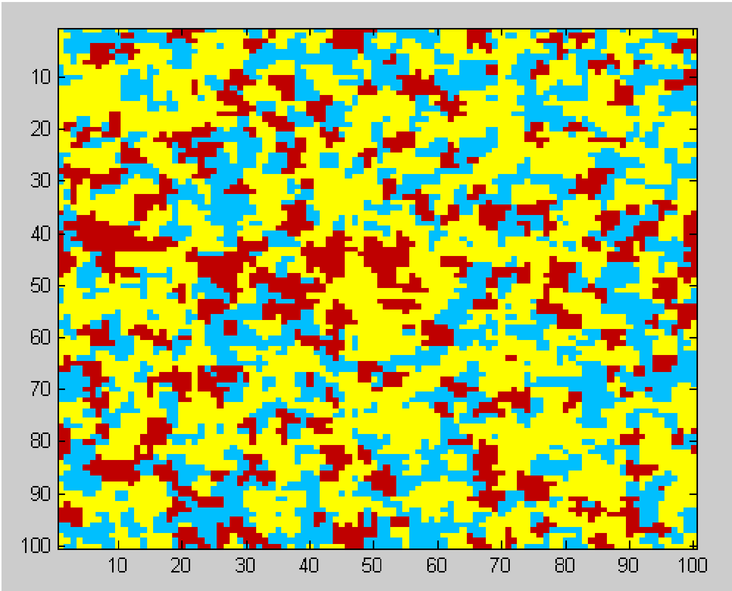


Figure 4

This is 10th iteration, shows that existed land state in urban area begins to spread to its surrounding. Further that spread is still can be observed to its initial condition and also the emergence of new land state group, what is called suburb.

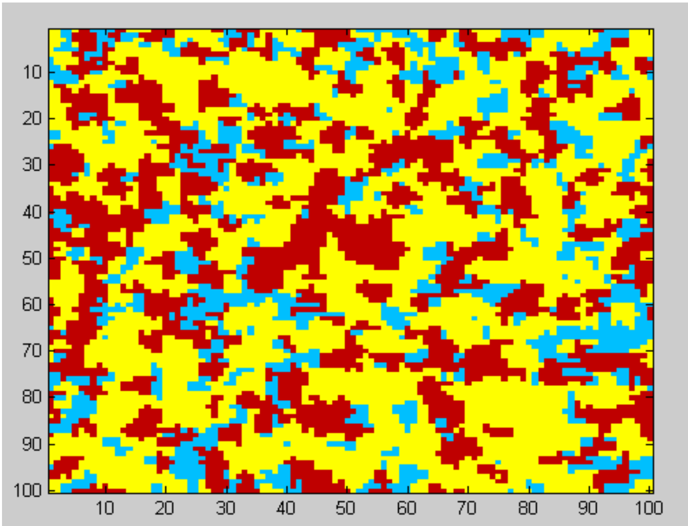


Figure 5

This is 15th iteration, shows that urban area structure has spread, so thus not only urban center becomes bigger but there are now new colonies that have almost the same characteristic like in urban center

4. Conclusion

We look further to von Thunen's agricultural economic location theory, simply in simulation shown that agricultural area which is closer to urban area will decrease step by step and is replaced by economy activities which is closer to urban area.

This simulation result also shows the emergence of new group economy activities. This is because of neighborhood factor which influences to change condition an area. In other word, the change of an area is more caused by neighbor's influence.

Simulation in this paper is a very simple simulation type, needed to develop furthermore, such as using in-constant Markov matrices and irregular area or map based.

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