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SISTEM BUCKET SEBAGAI ALTERNATIF SIMULASI PERTUMBUHAN KOTA DENGAN MODEL BERBASIS AGEN

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ABSTRAK

Urbanisasi adalah salah satu permasalahan yang dihadapi oleh banyak pemerintahan kota. Penduduk perkotaan cenderung untuk terus bertambah yang menghendaki lebih banyak lahan untuk pemukiman dan kegiatan lain. Memperkirakan pola pertumbuhan kota merupakan salah satu tantangan bagi para perencana kota. Model-model telah dikembangkan oleh banyak peneliti dan praktisi untuk memberikan gambaran mengenai kemungkinan bentuk masa depan dari sebuah kota. Makalah ini bertujuan untuk menerangkan dasar-dasar dari model *Bucket*, yang akan menempatkan penduduk baru di area yang sudah terbangun terlebih dahulu sebelum melimpah ke area kota yang kurang terbangun dan akhirnya ke area pinggiran kota. Model ini menggunakan peta grid sebagai area kerja dalam Model Berbasis Agen (MBA). Setiap sel peta grid dilengkapi dengan data tata guna lahan, densitas populasi, dan lainnya yang dapat dipakai untuk menunjukkan keunggulan dibandingkan dengan sel lainnya. Penduduk baru sebagai agen dapat berpindah secara bebas diantara sel-sel peta grid hingga menemukan sel yang paling tepat. Aturan-aturan perlu diterapkan pada setiap sel guna mengatur tingkat pertumbuhan. Makalah ini memberikan gambaran mengenai ide awal suatu pengembangan model pertumbuhan penduduk yang berbasis ABM.

Kata kunci: *Model Pertumbuhan Kota; Model Berbasis Agen; Urbanisasi; Peta Grid; Sistem Informasi Geografis*

BUCKET SYSTEM AS ALTERNATIVE OF URBAN GROWTH SIMULATION USING AGENT BASED MODEL

ABSTRACT

Urbanization is a common issue faced by many authorities. Urban population is steadily growing which requires more land for housing and other activities. Predicting urban growth pattern has been challenging efforts for planners. Many models have been developed by various researchers and practitioners to give a glimpse of possible future lookout of the city. This paper attempts to explain the basic of Bucket model, where new inhabitants will fill the more developed urban areas then spill over to less developed urban area and finally to rural areas bordering urban regions. This model is using a grid map as patches in the Agent Based Model (ABM). Each grid cell is filled with land use, population density, and other data to show its advantages compared to others. New inhabitants as the agent can move freely among the grid cells until an appropriate cell is found. Restrictions should be introduced to for each cell to limit the growth. This paper shows the initial idea of an urban growth simulation using ABM.

Keywords: *Urban Growth Model; Agent Based Model; Urbanization; Grid Map; Geographic Information System*

1. INTRODUCTION

Urbanization is one of the most significant issues in many countries in the world. According to UN Habitat (2004), about 50 percent of populations will live in urban areas which makes urban policy-making is a complicated process. In addition, the rate of the urban population growth is more than that of the rural population (UN, 1997). Furthermore, Arsenault (2016) reported that by 2050 urban inhabitants could reach 2.5 billion, which is larger than current population of China and India. Urban planners will wrestle daily with more complex and contentious problems - traffic jams, the cost of housing, sprawl - as well as broader issues such as livable cities, economic vitality, social equity, and environmental preservation. Rapid urban growth leads to the change of land use and land cover in many metropolitan areas around the world. One attempt is to anticipate and to forecast future changes or trend of developments through urban simulation modelling.

There are many urban growth models have been developed using different kind of methods. SimCity – for example – which is developed by Maxis™ Company, is one kind of game that allows the user becomes an urban planner and has to manage the growth of a virtual metropolis. Although it actually didn't start off as a simulation game, but this game gives the opportunity to orchestrate the building and development of a city. Users could see how their dream city grows from a vacant land with only a limited budget and utilities into a city. This game incorporates the ideas of development strategies to encourage economic growth, build up the population of the city, and score a higher "approval rating" from the virtual citizens.

Another model that is being developed by researchers at the University of Washington, is the UrbanSim. This model utilizes computer to simulate how cities grow and refining technology that could help remove much of the guesswork from urban planning. “The UrbanSim project is researching ways of building a complete, flexible and scalable microsimulation of urban growth (Reed, 2003).” By using the microsimulation, researchers try to map the growth of a city based on transportation, zoning, environmental regulation and other domains affect development and the quality of urban life.

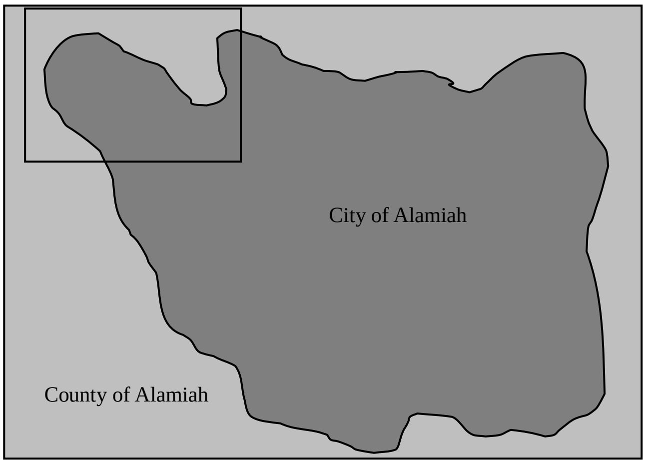
This paper attempts to introduce another method in explaining urban model using an agent based modelling concept.

2. METHOD

Urban growth model is always been a challenging field because cities evolve in complex and often unexpected ways. Therefore, there is always an opportunity to develop new models using different approaches (Guizzo, 2003; Reed, 2003; Teerarojanarat, Fairbairn, & Chunithipaisan, 2004; Rui, 2013). This paper tries to show the potential area for population to grow in the next future using a “Bucket” system. In this system, additional inhabitants of a city will first occupy the developed urban area which will be called as “Area A”, then the overflow will fill the area adjacent to area A which will be called as “Area B”, and lastly they will fill the area adjacent to area B which will be called as “Area C.” Conservation area should be excluded from any development within those three areas. Area C is preferred to be an existing agricultural site, which will be converted into urban area after the adjacent area is developed.

The Bucket system implements a grid structure of a city area. The grid pattern is a uniform square tiles that somewhat similar to the chessboard pattern on the Agent Based Model (ABM) environment (Brunner, 2010; Brunner, 2016; Coella, Klopfer, & Resnick, 2001). Several literature are describing the use of ABM in simulating urban growth (Benenson & Omer, 2004; Kohler, Van West, Carr, & Langton, 1996.; Kim, 2012; Magliocca, N., McConnell, V., Walls, M., & Safirova, M., 2012). Acting as the agents in this proposed system are the inhabitants of a city. The agents will interact with the patches, in this case are the grids which each of them has different characteristics based on its land use, population density, and other variables. The agents, basically, can move freely among patches until they find the appropriate patch locations for them to stay. However, agents can only stay in a particular patch if the patch has not reached its limit in storing the agents.

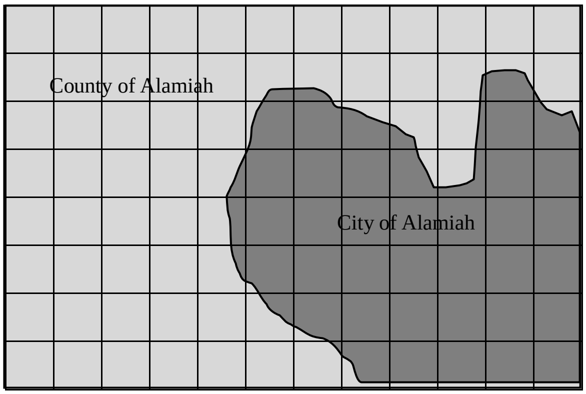
2.1 Development of grid map system



Source: Author analysis

Figure 1. Map of The City and County of Alamiah

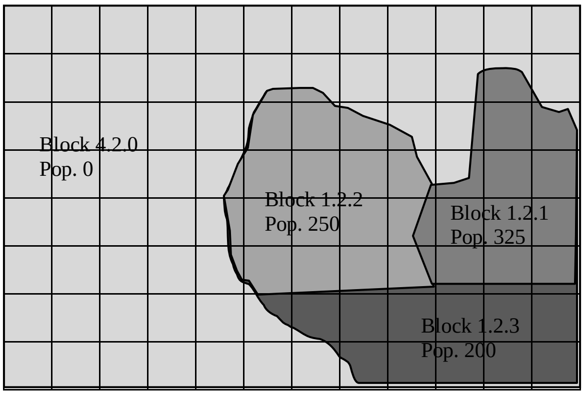
There are several steps to be taken to develop this system into the ABM environment. The steps begin with creating a grid structure in a uniform size covering the whole area of the city. Figure 1 depicts the boundary of the city of Alamiah which surrounded by the county of Alamiah, and figure 2 depicts the zoom in area which is overlaid with a rectangular grid structure.



Source: Author analysis

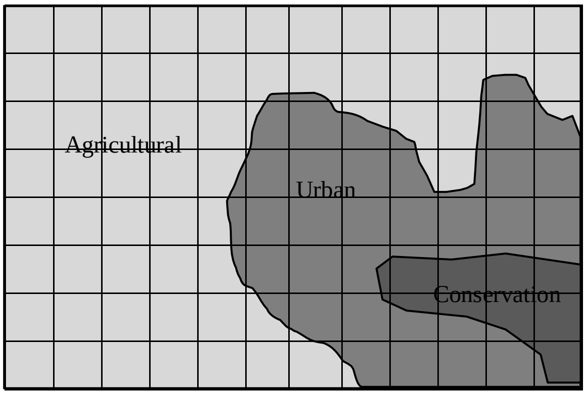
Figure 2. Grid Structure of Part of The City and County of Alamiah

Each grid cell will be analyzed using several thematic maps of the area, such as: population, land use, zoning, parcel, and other maps that related to population distribution in the area. Assuming that the first two maps are available and the shape of each map is depicted as follows:



Source: Author analysis

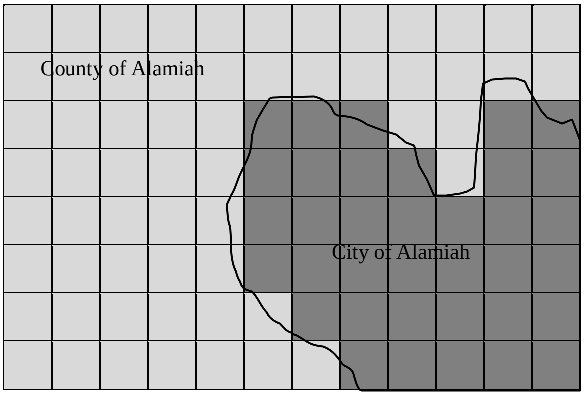
Figure 3. Population Map with Grid Structure



Source: Author analysis

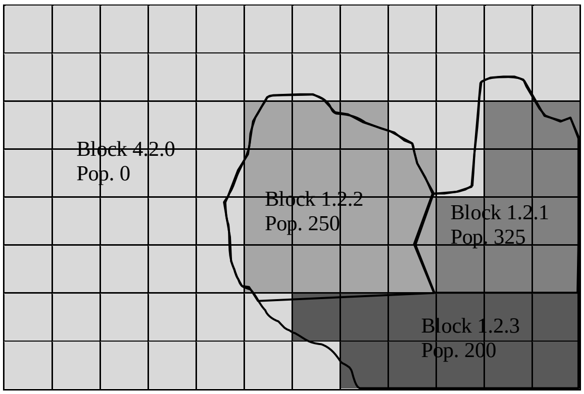
Figure 4. Land Use Map with Grid Structure

The administrative (see Figure 2), population (see Figure 3) and land use maps (see Figure 4) can be converted into grid maps by allocating the map attributes within each grid cell. However, a problem exists for grids that do not have a 100% coverage area over a category. For example: Grid F2, about 10% of its area belong to the City of Alamiah while the rest belong to the County of Alamiah; Grid I6, 10% of its area belong to Block 1.2.1 and the rest to Block 1.2.2, and 20% is designated as Urban area and the rest as Conservation Area. In such cases, the grid should follow the characteristic of the majority attribute, which means that grid F2 should be categorized as part of the County of Alamiah, and grid I6 should be part of Block 1.2.2 and be categorized as conservation area. By using mentioned method, maps in figures 2, 3, and 4 can be changed as depicted as follows:



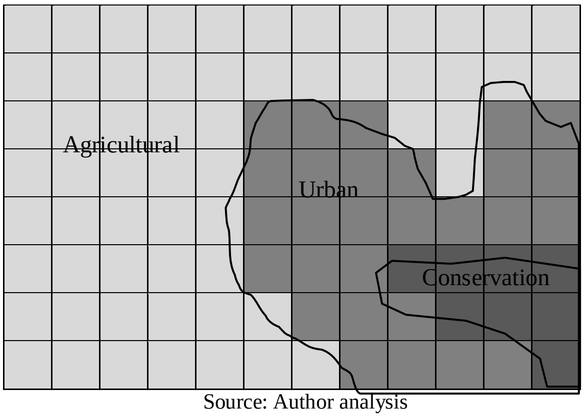
Source: Author analysis

Figure 5. Administrative Grid Map



Source: Author analysis

Figure 6. Population Grid Map

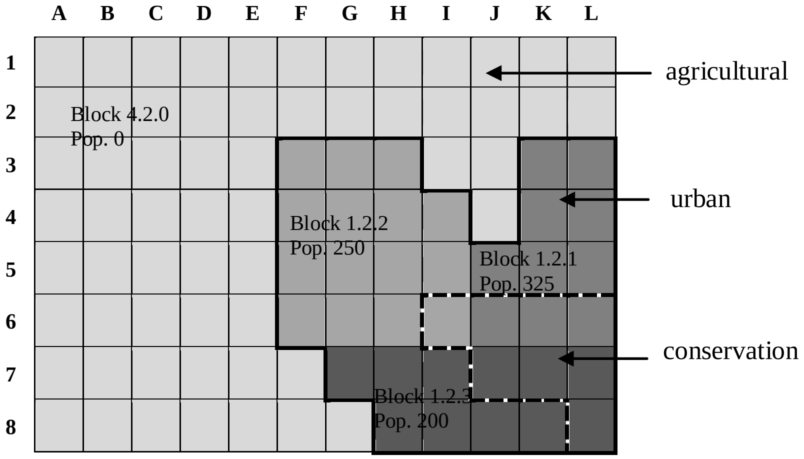


Source: Author analysis

Figure 7. Land Use Grid Map

2.2. Development of patches for agent based model

The administrative (see figure 5), population (see figure 6) and land use (see figure 7) grid maps can be overlaid one to each other to give more information by grid level. The composite grid maps is depicted in figure 8. Each inhabited grid will have population based on number of people recorded in each block divided by total number of grid within the block. An attention should be brought up with the grids within the conservation area. Since nobody should live in it, population of blocks 1.2.1, 1.2.2, and 1.2.3 will be distributed outside the conservation area. This means that – for example – each grid within block 1.2.1 will have 325 / 7 ≅ 46 persons instead of 325 / 10 ≅ 32 persons, since three grids of this block are within the conservation area. Note that the population number for each grid is rounded, and this rounding method will be applied on every calculation involving population. Rounding is necessary since agent cannot be divided into a fraction. However, because of this rounding, the sum of population from all grids most likely will not be the same as the total population before it distributed into grid level.



Source: Author analysis

Figure 8. Composite Grid Map

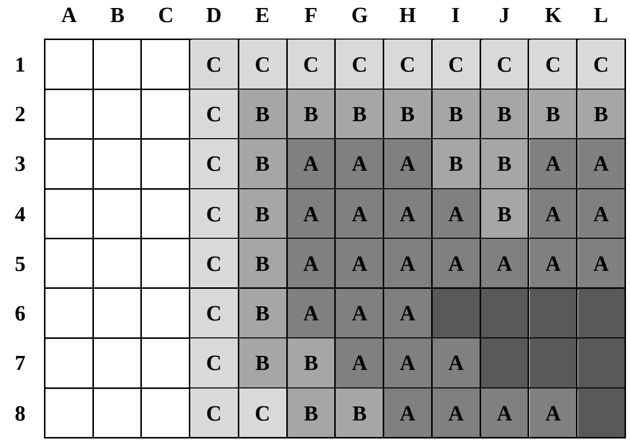
Information on grid level from the figure 8 can be collected as shown on the following table.

Table 1. Summary Information of the Composite Grid Map

Grid	Population per grid	Land Use
A1 to L1; A2 to L2; A3 to E3, I3, J3; A4 to E4, J4; A5 to E5; A6 to E6; A7 to F7; A8 to G8	0	Agricultural
F3 to H3; F4 to I4; F5 to I5; F6 to H6	18	Urban
K3 to L3; K4 to L4; J5 to L5;	46	Urban
G7 to I7; H8 to K8	29	Urban
I6 to L6; J7 to L7; L8	0	Conservation

Source: Author analysis

Information from figure 8 and table 1 above can also be interpreted as area A, B, and C. Area A is for developed urban area; Area B is less developed urban area and area adjacent to A; and Area C is for agricultural land that will be converted into urban area and located next to B. Several adjustments should also be made to exclude from being developed, such as conservation zones or area for sensitive infrastructures (airports, seaports, highways, military areas, and such). The results of conversion into area into ABM patches is depicted as follows:



	A	B	C	D	E	F	G	H	I	J	K	L
1				C	C	C	C	C	C	C	C	C
2				C	B	B	B	B	B	B	B	B
3				C	B	A	A	A	B	B	A	A
4				C	B	A	A	A	A	B	A	A
5				C	B	A	A	A	A	A	A	A
6				C	B	A	A	A				
7				C	B	B	A	A	A			
8				C	C	B	B	A	A	A	A	

Source: Author analysis

Figure 9. Distribution of Area A, B, and C

In the ABM environment, the distribution of Area A, B, and C as depicted in figure 9 can be represented in the form of several patches using different colors. The existing population on each grid can be represented by allocating an exact number of agents on each patch. The coordinated system of the ABM environment can be used to determine the location of each patch, and the create agent function can be used to allocate number of existing population on each patch.

3. RESULTS AND DISCUSSION

Assume that the current population of the city of Alamiah is 10,000. Based on experts' calculation, the population of that city in the next 10 years would grow by 1,000. Allocation of the future population in the Area A, B and C can be determined – say – by the city planners or other decision makers based on allowable development in mentioned areas. For example, they decided that Area A in the next ten years will be allowed to absorb 20% of the new population, which means Area A can absorb up to 1,000 times 20% = 200 new inhabitants. Area B will be allowed to absorb up to 60% or 600 new inhabitants, and the rest (200 inhabitants) will go to area C.

After allocating new inhabitants into area A, B, and C, the next question that will appear is how to distribute them within each area. There are some possibilities: a) distribute them evenly. For example there are 50 patches that represent 50 grids of Area A, and there are a-200 new inhabitants. This means that each patch will have four new inhabitants; b) distribute them based on the attractiveness index of each patch. For example, within Area A, grids that closer to the city center will be more attractive than the further ones, and grids that have less density will be more attractive than the denser ones. Creating an attractiveness index from those two aspects will allow new inhabitant to spread unevenly, which is more realistic than distribute them evenly. However, creating an attractiveness index for each patch could be a complicated process. For instance, creating an attractiveness index for Area A, B, and C is different, since area B and C do not have any existing population. The next section will explain the concept of creating attractiveness index for each type of area.

Attractiveness index for area A will be determined by at least two factors, distance to the city center and current population density. First of all, the location of the city center should be determined. Distance from each grid or patch to the city center could be calculated. In case that the ABM software cannot calculate the distance from a point to many points, then Geographic Information System (GIS) software would be useful. For example, distance from the city center to patch G6 and G7 is 10 units, and to patch K8 is 8 units. Population density for each grid is directly represented by the population number since the area of each grid is the same, where G7 and K8 each has 29 inhabitants and G6 has 18 inhabitants. Distance index is determined using the following formula:

Distance Index for patch i = Distance to patch i from city center / distance from city center to the furthermost grid within Area A (1)

Population index is determined using the following formula:

Population Index for patch i = 1 – (Number of inhabitants in patch i / maximum inhabitants among grids within Area A) (2)

The attractiveness index for each grid within Area A can be calculated as a composite of those previous indexes and applying weighting factors. Weighting factors can be determined using a simple comparison such as how important this factor to the other. For example, distance is 2 times more important than population density. This means that the maximum contribution of population index to the attractiveness index is 1/3. The Attractiveness Index is determined using the following formula:

Attractiveness Index = (Distance Index * Distance Index Contribution Factor) + (Population Index * Population Index Contribution Factor) (3)

Assuming that the maximum distance from city center to the furthermost patch within Area A is 100 units, and the denser patch within Area A is 100 inhabitants, the index for those three grids can be illustrated as depicted on table 2 below.

Table 2. Attractiveness Index Calculation for Area A

Patch or Grid	**Distance to city center**	**Distance Index**	**Population density**	**Population Index**	**Contribution to the attractiveness index**		**Attractiveness Index**
					Distance	**Population**	
G6	10	0.10	18	0.82	2/3	1/3	0.340
G7	10	0.10	29	0.71			0.303
K8	8	0.08	29	0.71			0.290

Attractiveness index for area B will be determined by at least two factors, distance to the city center and average population density of grids within Area A adjacent to a particular grid within area B – which will be called as “calculated population”. The distance index for Area B is using the same method as the one for Area A. The calculated population index is determined using the following formula:

Calculated population Index for patch j = 1 – (calculated population in patch j / maximum calculated population among grids within Area B) (4)

The calculated population is determined using several possibilities:

a. If patch *j* within Area B only share border with one patch from Area A. The calculated population for patch *j* is the population of mentioned patch from Area A. For example, calculated population for patch E7 = population of F6 (see figure 9)

b. If patch *j* within Area B is located adjacent to two or more patches from Area A. The calculated population for patch *j* is the average of the population of all adjacent patches from Area A.

For example (figure 9), calculated population for patch H2 = (population of G3 + population of H3) / 2. Calculated population for patch J4 = (population of I4 + population of I5 + population of J5 + population K5 + population K4 + population K3)/6.

The calculation to determine calculated population could be done easier by using GIS software, and later the result can be converted into the ABM environment.

Lastly, the attractiveness index for area C will also be determined by at least two factors, distance to the city center and average population density of grids within Area B adjacent to a particular grid within area C – which will be called as “calculated population”. The distance index for Area C is using the same method as the one for Area A or Area B. The calculated population index is determined using the following formula:

Calculated population Index for patch k = 1 – (calculated population in patch k / maximum calculated population among grids within Area C) (5)

The calculated population for Area C is determined using the same rule as applied to calculate the calculated population for Area B.

The attractiveness index will be applied in the ABM environment as a determinant factor of how many new inhabitant can be absorb by each patch. It is assumed that Area A in the next ten years will be allowed to absorb 200 new inhabitants, Area B absorb 600 new inhabitants, and 200 others to area C. Assume that based on calculation that the sum of attractiveness indexes for Area A is 119.70, for Area B is 58.43, and for Area C is 76.30. Therefore, new population that will be absorbed by patch within Area A can be determine as the following example:

Table 3. Calculation to Determine New Inhabitants

Patch or Grid	Attractiveness Index	Total Allowable New Inhabitant	Total Attractiveness Index for Area A	Allowable New Inhabitants on Each Grid
G6	0.340	200	119.70	(0.340/119.70)*200 = 0.57 ≅ 1
G7	0.303			(0.303/119.70)*200 = 0.51 ≅ 1
K8	0.290			(0.290/119.70)*200 = 0.48 ≅ 0

The same method also applies for calculating allowable of new inhabitants on each grid within Area B and C. Nevertheless, because of number rounding process, there is a possibility that the sum of allowable new inhabitant on each grid within an Area will not match with the total allowable for mentioned Area.

After knowing the allowable of new inhabitants on each grid, this number will be attached to the grids or patches. Since the movement of the agent in the ABM environment is random, there is a possibility that the agent will visit not all patches within each Area, which allowed to be filled with new inhabitants. On the other hand, if all of the patches within an Area are filled, the distribution pattern is actually known from the first beginning making the simulation no longer interesting. To overcome this problem and to increase flexibility of agent movement, the allowable of new inhabitants on each grid will be multiplied by two or three. The process of filling up the new inhabitant on each Area, however, will stop after reaching the total allowable of new inhabitants for mentioned Area. This will also overcome the previous problem that the sum of allowable new inhabitant on each grid within an Area will not match with the total allowable for mentioned Area. The simulation will completely stop after all Areas have been filled with the new inhabitants.

4. CONCLUSION

Probably after running the simulation for several times, the results will show some tendencies that the growth will occur in several locations or they will be totally random. Nonetheless, it is understood that this proposed model is still in an early stage of development. Therefore, the results could not be used directly as an indicator that in the reality the growth will occur in particular locations. The simulation might be show a more realistic result if more variables are applied in determining the attractiveness index, such as roads network, land value, crime rate, point of interest (malls, schools, parks, etc). The simulation is indeed designed as a deterministic model. Planners and experts will play serious roles in deciding pattern of the patches. This probably true in well developed countries, where land use and zoning have been determined and implemented. In countries where urban growth pattern is more organic and less planned, this simulation would face more challenging issues. Another additional computation, including Monte Carlo repetitions aimed at estimating the variation of results, could increase model's performance.

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