Transition Rule Mining of Cellular Geography Model Using Map Sequence and Spatiotemporal Series Analysis Approach

Ahmad Zuhdi, Aniati Murni Arymurthy, Heru Suhartanto, Maruli H. Manurung

***Abstract*— Transition rules elicitation is an important issue in modeling of spatiotemporal dynamics of the Cellular Geography model, because the transition rule is an engine of the system dynamics. The rule calculates the value of current cell, based on cell value and the value of its neighboring cells at the previous time. We propose the transition rules of the model, using multiple linear regression analysis, by performing adjustment of model parameters and input data. Data in this research is a collection of JPEG images of maps that present the results of observations of drought code variable in Fire Danger Rating System for 30 successive days. In order to process the data in the model Continues Cellular Geography, the qualitative input data was transformed into continuous data using random number generator based on certain probability distribution. The research observed the effect of the selection of neighborhood scheme and its radius, to the quality of transition rules. Experimental results show, continues uniform distribution is better than normal distribution and uniform discrete distribution. Whilst in the scheme of Cellular Automata model, von Neumann neighborhood with radius 2, is the optimal scheme. Manipulation of map resolution, by up grading or down grading it's scale, can be decreasing the quality of transition rules. Unfortunately, this research hasn't found the parameter setting, which has no significance of external variation, except of 2 cases.**

***Index Terms*— Transition Rule, Continues Cellular Geography, Spatiotemporal Series Analysis, Random Number Generation, Multiple Linear Regression Analysis**

I. INTRODUCTION

The development of geospatial information technology has rapidly increased impact on users' needs for knowledge about change and movement. The flood of geospatial information on global networks has improved the need for empowering geospatial knowledge into more meaningful and useful for users. However, sometimes users are faced with very limited availability of data and knowledge, both in terms of quantity and quality. The problem is, although there are spatial data floods, but the analysis tools and non-spatial applying quantitative methods are still scarce. Sometimes the source of the quantitative data of geospatial information is expensive to acquire. Hence it is necessary initiatives to regain the quantitative value of these geospatial data. The knowledge deals with the place in geographical location and time referenced; because the entity recorded in the database 80% have a geographical reference [7]. Today, visualization of temporal dynamics of the system based on geographical knowledge, become more important and interesting to study [2]. The Change of geospatial object is presented in the form of spatiotemporal trend, which requires modeling spatiotemporal. The model presents the relationship between each of cell in the grid with the cells surrounding it, and it value change regularly.

However, sometimes users are faced with the increased availability of data, but the knowledge is very limited, both in terms of quantity and quality. They need to find an alternative of systems dynamics modeling, with minimal effort, i.e. with the available data potluck able to explore implicit knowledge with quite satisfactory or optimal, without the need for complex expert knowledge. According to the increase of map publications on the web, the availability of geospatial data and information has increased dramatically. So the user scan acquire knowledge of geospatial and temporal more easier. However, qualitative information is not sufficient to explore spatiotemporal dynamic of geographic data using quantitative methods, such as Continues Cellular Automata model. The quantification of qualitative data to perform more in-depth exploration of knowledge becomes the first driving force to do this research.

II. TRANSITION RULE FORMULATION

The model of Cellular Geography presents the geographic data dynamics implicitly through the transition rules of Cellular Automata model. The formula defines the state of each cell at a certain time step, as the linear combination of the states of its neighborhood, at previous time step. It depends on the choice of neighborhood schema and it's radius. There are two popular schemas applied in this model, i.e. von Neumann and Moore. [5][8]

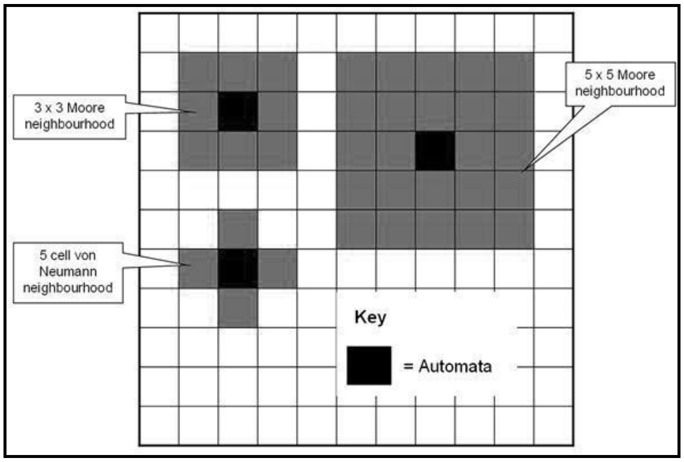

Figure 1
Neighborhood Schema of 2D Cellular Automata Model [10]

Formulation of transition rules depending on the choice of neighborhood structure (its shape and radius) and the formula for the contribution of neighboring cells. The contribution of neighboring cells for the cell values that are evaluated based on the Scheme of Von Neumann and Moore's scheme is different, as shown in Figure 2.

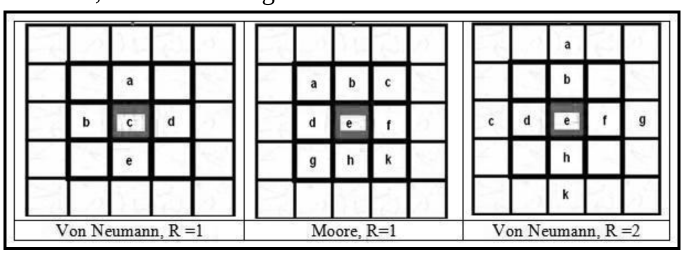

Figure 2
Three famous scheme of Neighborhood cell contribution

Refer to the value contribution in figure 2, can be formulated in a simple transition rules for R = 1, by applying the outer totalistic approach obtained the following formula:

a) von Neumann’s scheme

$$S_{ij}(t+1) = (a.S_{i-1j}(t) + b.S_{ij-1}(t) + c.S_{ij}(t) + d.S_{ij+1}(t) + e.S_{i+1j}(t) \quad (1)$$

b) Moore’s scheme

$$S_{ij}(t+1) = (a.S_{i-1j-1}(t) + b.S_{i-1j}(t) + c.S_{i-1j+1}(t) + d.S_{ij-1}(t) + e.S_{ij}(t) + f.S_{ij}(t) + g.S_{i+1j-1}(t) + h.S_{i+1j}(t) + k.S_{i+1j+1}(t) \quad (2)$$

We can formúlate extended von Neumann for R=2, by modifying equation (1) and the structure of it’s scheme in figure 2. The above equations show, that transition rule is equivalent with the vector of coefficient of linear combination of the cell value and it’s neigbor values. The vector can be estimated with multiple linear regression analysis.

Cellular Geography approach has been formulated through several transition rules for the various domain issues [5] [3] [4]. *Fuzzy Cellular Automata Urban Growth Model* (FCAUGM) is a model of CA that are generated with fuzzy logic to model the growth of Riyadh [1]. *Beijing Urban Developing Model* (BUDEM) implementing the integration of logistic regression with MonoLoop, to determine the value of the weight on the transition rules [5], the AHP-GIS-CA model in combination with probability-based decision making tool, *the Analytic Hierarchy Process,* for irrigation planning and land use in Australia [7]. All of them use geographic data to evaluate the multi-layer multi-criteria optimization.

III. MULTIPLE LINEAR REGRESSION ANALYSIS

Regression analysis provides model of the mathematical relationship between the dependent variable y, with one or more independent variable x. A multiple linear regression model has at least 2 independent or predictor variables, and applying the concept of simple linear regression analysis with slight modifications [9].

A multiple linear regression model has k independent variables x_1, x_2 ... x_k *which can be represented as follow:*

$$y = \alpha + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k + e \quad (3)$$

α , β_1, β_2, ... , β_k are the parameters of the model to be estimated based on the given data set. *where* e is computation error. Independent variables are random variables, x_i has a normal distribution N (μi, σi), for i=1,2, . . . , k.

The most popular method applied to estimate the parameters of the model is the least squares estimator, which was developed by Gauss, by finding a hyper plane in the space dimension (k +1), which has minimum value of e^2:

k random variables above, are mutually independent and each of x_i variable has normal distribution N (μi, σi),).

$$e^2 = \sum [\, y - (\alpha + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k) \,]^2 \quad (4)$$

On the transition rule formula, the value of α is zero. It should be no contribution of external variation, except of their linear variables. So we should find the model which has no significance value of α. Statistically, we can tested the hypothesis with student t statistics, as well as the significance of predictor variables. Test of the all parameter model simultaneously can be provided by F statistics.

The quality of regression model is represented by the determination coeficient or R square, which is defined as the ratio between sum of regression difference square and sum of response square. Related to the regression, a good transition rule has 2 criteria, first it has high R-square, the value close to maximum, i.e. 1, and the second, the first regression coefficient related to constant is not significant, that means the value can be neglected.

IV. CASE STUDY

This paper will present the model of spatiotemporal exploration of geographic knowledge, from a series of JPEG format image maps, data from successive time at a certain period of time, to obtain the dynamic behavior of Fire Danger Rating System, as shown in Figure 1. As an illustration, the study selected a simple case study on the monitoring system of forest and land fires in Indonesia, based on fire danger rating system (FDRS) published by Indonesian Outer Space and Aviation Institute LAPAN (www.lapanrs.com). The observed area is taken in South Sumatra province and time of observation for 35 days, beginning July 1, 2009 until August 4, 2009. At this time, there was a significant change from a safe condition to the extreme conditions.

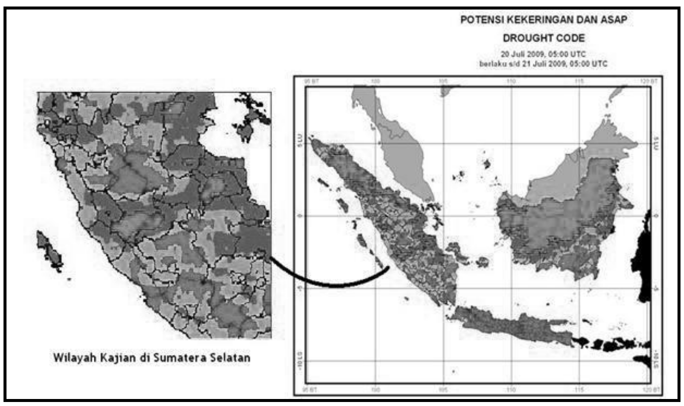

Figure 3
Sample Input Data on July 20th, 2009 [12]

Potential drought and smoke is a quantitative measure, valued at 000-500, the moisture content in the organic layer under the soil surface. Drought Code (DC) is used as an indicator of drought and the potential for smog. DC high ranking usually occurs on peat fires. Input data is provided in the form of qualitative data ordinal y ∈ {0, 1, 2, 3, 4}, each element presents one category, the results of classification based on the real variable x (0 < x < 500). Spatiotemporal knowledge exploration model is built based on the variable x, so the first problem is the need of mapping that returns the results of classification prior to the computation.
For presentation, information based on the DC classified in 4 categories with the following conditions:

Table 1 Classification of Drought Code (DC) [11]

KELAS	DC	INTERPRETASI (INTERPRETATION)
Rendah *(Low)*	< 140	**Kondisi musim basah,kabut asap tidak terjadi** *(Typical wet-season conditions and severe haze periods are unlikely. More than 30 dry days until DC reaches threshold at which point severe haze is highly likely)*
Sedang *(Moderate)*	140-260	**Kondisi normal pertengahan musim kering, pembakaran harus dipantau** *(Normal mid dry-season conditions. Between 15 and 30 dry days until DC reaches threshold. Burning should be regulated and monitored as usual)*
Tinggi *(High)*	260-350	**Kondisi normal puncak musim kering, seluruh pembakaran di atas lahan gambut dilarang** *(Normal dry season peak conditions. Between 5 and 15 dry days until DC reaches threshold. All burning in peatlands should be restricted. Weather forecast and seasonal rainfall assessments should be monitored closely for signs of an extended dry season)*
Ekstrim *(Extreme)*	>350	**Kondisi bahaya kekeringan, pembakaran sepenuhnya dilarang** *(Approaching disaster-level drought conditions. Less than 5 dry days until DC reaches threshold, at which point severe haze is highly likely. Complete burning restriction should be enforced)*

The quantification of qualitative data are illustrated in the map is conducted in 2 stages, namely image segmentation pattern and the transformation of values into the category of quantitative value. Segmentation image pattern was conducted to observe the dominant RGB value of the five categories of DC, as shown in Table 2. Transformation process of the data into quantitative values is provided by generating random numbers at each interval associated with each cell value as described in Table 3.

Table 2
Color Segmentation

No.	Color	Object	Code	Characteristic
1	White	Sea level	0	R> 200 and G>200 and B> 200
2	Blue	Surface Land / Forest, low DC	1	R <100 and G<100 and B>200
3	Green	Surface Land / Forest, moderate DC	2	R <100 and G>200 and B <100
4	Yellow	Surface Land / Forest, high DC	3	R> 200 and G>200 and B <100
5.	Red	Surface Land / Forest, DC extreme	4	R> 200 and G <100 and B<100

Table 3 Randomization Data Models

DC Class	Transformation to estimate DC
Low	Randomize (0, 140)
Medium	Randomize (141, 260)
High	Randomize (261, 350)
Extreme	Randomize (351,500)

V. EXPERIMENTS AND EVALUATION

Input data consist of 30 color images 211x212 pixels, then converted into thematic data with 5 categories of DC. Each cell or pixel has value categories as in Table 1, it is converted to random numbers, base on the rule in Table 2. From each pair of consecutive image constructed a transition rule, which presents the change of state from the first image to second image. So there are 29 transition rules.

A. Experimental Design

The exploration of transition rules, by applying the technique of data mining is implemented by observing and comparing the transition rules with multiple linear regression analysis. Comparison of treatment parameters is set based on input data and model parameters Cellular Automata. There are four parameters measured as experimental treatment, i.e. the selection of random number generators, the selection of data resolution, neighborhood scheme and its radius.

For the first trial, von Neumann neighborhood scheme, with radius R = 1 is selected, then compared the performance of three difference generator random selection, the model according to the normal distribution, discrete uniform distribution and continues uniform distribution. Now we know the best random generator model, compared between Moore scheme with the scheme of von Neumann with a radius R = 2, because the both have same computational complexity, which involves the calculation of 9 cells. Finally, we observe ratio between the size of spatial data in small size (148x148 pixels) and large size (317x318 pixels).

Input data set has 30 data grids, which can be manipulated with multiple linear regression analysis into 29 time series trend. Each trend describes a transition rule pairs, wrt Neighborhood scheme and random generation method. We can evaluate it's quality, by examine (1) the significance of $\boldsymbol{\alpha}$, with student t test, and (2) significance of $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ respectively, with F test, and (3) the value of R square.

B. Experimental Results

Number In all of case study that has been observed, all of transition rule has fulfilled significance of all regression coefficients, through F test. The F test values greater than F table values as seen in the Table 4, which is indicate the worst experimental result, for Moore neighborhood scheme (degree of freedom for t-test is 43890 and F-test is 43890 and 9).

Table 4
Transition Rules for Moore scheme with R=1

TR Pair	Regession Quality (R2)	Constant Coefficient (bo)	bo Test: t Statistic	bo Test: t-Table	Regression Coefficient Test: F-Statistic (e+03)	Regression Coefficient Test: F-table
1	0.6064	16.8971	10.9831	0	7.5123	0
2	0.6139	28.3980	19.2253	0	1.7771	0
3	0.2671	186.7189	97.3756	0	1.7771	0
4	0.2835	90.5468	39.7841	0	1.9288	0
5	0.5426	32.5953	19.9164	0	5.7844	0
6	0.5548	40.3933	25.7966	0	6.0755	0
7	0.6173	18.2771	12.2889	0	7.8632	0
8	0.5362	40.5691	25.0798	0	5.6365	0
9	0.5417	26.3129	15.8663	0	5.7633	0
10	0.5764	42.7152	27.6122	0	6.6349	0
11	0.6298	22.5303	15.2902	0	8.2952	0
12*	0.5271	503.8029	334.7747	0	5.4347	0
13	0.8211	3.4794	6.8071	0	2.2372	0
14	0.6333	14.3678	19.3520	0	8.4220	0
15	0.7958	5.0961	9.5261	0	1.8997	0
16*	0.2510	505.7240	458.3178	0	1.6336	0
17	0.6508	30.1524	21.0794	0	9.0857	0
18	0.6761	26.1549	18.9776	0	1.0177	0
19	0.6771	31.4378	22.8039	0	1.0224	0
20	0.6982	25.5291	18.9656	0	1.1280	0
21	0.5334	52.0345	30.1624	0	5.5744	0
22 w	0.2657	104.5774	45.8509	0	1.7646	0
23	0.6263	12.8348	8.6587	0	8.1698	0
24*	0.5592	491.6650	359.9030	0	6.1851	0
25	0.7888	5.4909	9.8127	0	1.8212	0
26*	0.2431	513.8655	439.1747	0	1.5658	0
27	0.5260	53.5289	31.5022	0	5.4101	0
28	0.6168	25.1683	16.4208	0	7.8476	0
29	0.6431	21.2843	14.4170	0	8.7870	0

Based on the detail compilation of it's experimental result, there is 4 cases of ill condition of transition rule in this case, namely in TR 12, 16, 22, and 24.

16* The regression coefficient isn't significance since t-test statistic (-11.1461 -7.6311 -6.7065 -5.0420 -9.1000 -3.9765 -8.1984 -5.5712 -8.9545) less than t-table values 1.0e-004 * (0.0000 0.0000 0.0000 0.0046 0.0000 0.7005 0.0000 0.0003 0.0000)

22w R square value relatively small, however the regression coefficient isn't significance, since t-test statistic (10.1439 9.1020 11.2809 5.3003 18.5178 9.0383 8.2750 7.8692 9.3097) greater than t-table values 1.0e-006 * (0.0000 0.0000 0.0000 0.1162 0.0000 0.0000 0.0000 0.0000 0.0000)
12* and 24* although R square relatively large, but all of regression coefficient isn't significant. For 24th TR t-test statistic (-23.7226 -20.5962 -25.0760 -18.5511 -27.4972 -19.3605 -20.8827 -19.2690 -22.2170) less than t-table values 1.0e-075 * (0.0000 0.0000 0.0000 0.1570 0.0000 0.0000 0.0000 0.0000 0.0000)

According to random number generator method, from figure 4 we can identify, that in this case uniform continues distribution is better then normal distribution and uniform discrete distribution.

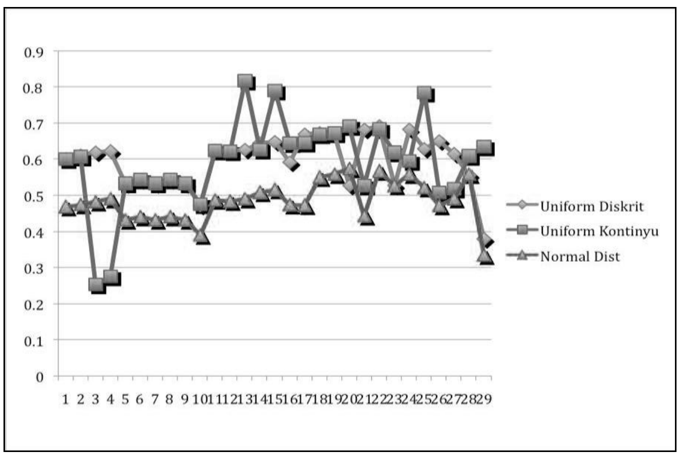

Figure 4
Comparison of 3 random generation methods

As shown in figure 1, simple von Neumann scheme has 5 cells that should be calculated. To improve it's quality we can explore it by extending it's radius from 1 to 2 or choosing other scheme, such as Moore neighborhood in the same radius size which has 9 cells to be evaluated. Figure 5 shows the performance comparison between simple von Neumann, Moore scheme and extended von Neumann.

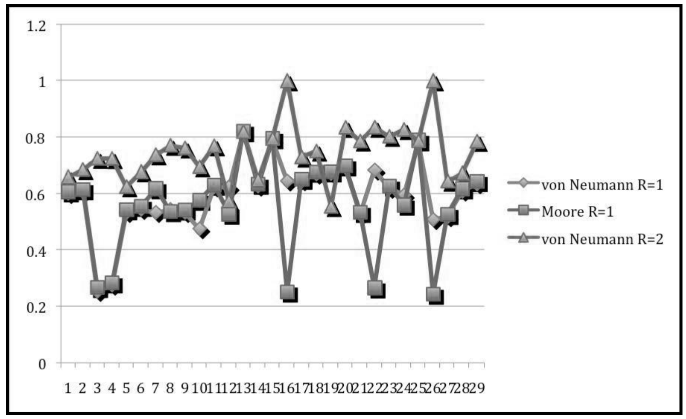

Figure 5
Performance comparison of 3 neighborhood schemes

The extended von Neumann scheme has best performance for representing transition rules and Moore scheme has the worst. Extended von Neumann scheme also has 2 pairs of transistion rule with maximum performance, i.e. 16th and 26th pairs, as shown in the detail information in Table 5. All variations of transition rules, in that 2 cases, can be represented perfectly by 9 cells of the model. This representation is the ideal, since it has fulfilled the criteria for best transition rule, i.e. maximum values of R square (equal 1) and insignificancy of constant value of regression coefficient.

Table 5
Transition Rules for Extended von Neumann scheme

TR Pair	Regression Quality (R2)	Constant Coefficient (bo)	bo Test		Regression Coefficient Test	
			t Statistic	t-Table	F Statistic	F-Table
1	0.6593	10.5420	15.3843	0	9.2549	0
2	0.6854	21.2689	32.1250	0	1.0419	0
3	0.7250	5.4424	8.7491	0	1.2607	0
4	0.7243	13.2266	21.8392	0	1.2565	0
5	0.6245	13.7719	18.6692	0	7.9557	0
6	0.6776	14.4439	21.6293	0	1.0054	0
7	0.7377	5.1453	8.6204	0	1.3450	0
8	0.7713	7.8174	14.1563	0	1.6127	0
9	0.7619	3.9530	6.9648	0	1.5304	0
10	0.6952	8.8665	12.9304	0	1.0911	0

11	0.7695	4.8038	8.1425	0	1.5970	0
12	0.5734	42.3282	55.3546	0	6.4292	0
13	0.8197	2.5997	4.9716	0	2.1749	0
14	0.6485	13.1299	17.6854	0	8.8254	0
15	0.7950	4.1422	7.5820	0	1.8545	0
16	1	0.0000	1.0e+017 * 0.0000	0	1.4748e+035	0
17	0.7294	15.4636	25.2617	0	1.2892	0
18	0.7508	19.0304	32.3012	0	1.4413	0
19	0.5543	18.8363	23.3766	0	5.9478	0
20	0.8349	3.6050	7.3839	0	2.4184	0
21	0.7865	5.4095	9.5413	0	1.7620	0
22	0.8352	3.2367	6.5736	0	2.4247	0
23	0.8031	3.4857	6.3938	0	1.9511	0
24	0.8273	5.3383	10.4573	0	2.2915	0
25	0.7870	4.7460	8.2838	0	1.7667	0
26	1	0.0000	1.0e+017 * 0.0000	0	7.9440e+034	0
27	0.6440	13.3275	17.3163	0	8.6519	0
28	0.6727	12.8683	17.4180	0	9.8293	0
29	0.7854	3.2657	5.6562	0	1.7505	0

Final observation is exploring the chance to improve quality, based on their determination coefficient or R square, by manipulating the spatial data resolution. Figure 6 shows performance comparison of 3 resolutions variation.

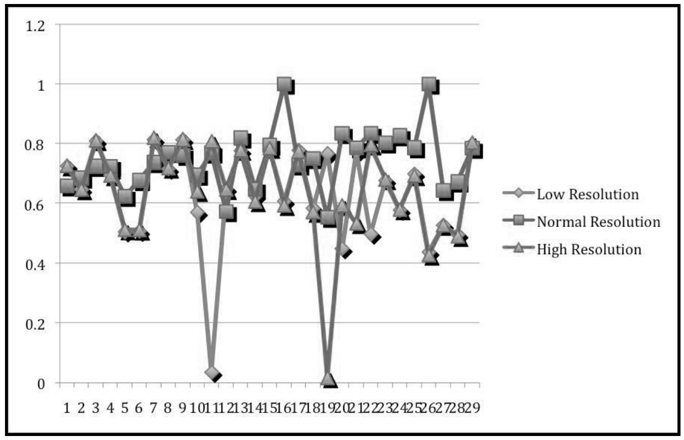

Figure 6
Performance Comparison of Low Resolution (148x148 pixels), Normal (211x212 pixels) and High Resolution (317x318 pixels) of Input Data

Normal size maps gives optimal transition rules, whilst the effort to manipulation it by improve it resolution gives worst result. The map in low resolution gives better transition rules than high resolution.

VI. CONCLUSION

Transition rule of Cellular Geography model can be extracted from set of input data grid, qualitative or quantitative, through linear multiple regression analysis. The qualitative data can be modified into quantitative by applying random number generator. The regression analysis applied to each pair of subsequent grid. Performance of the model is evaluated with determination coefficient or R-square and its t and F statistic signifance test. The experiment has been evaluated model performance based on random generator method, neighborhood scheme and resolution of input data. From the data that has been observed in the case study, we has shown that von Neumann scheme has better performance in exploring transition rule of cellular geography model, although it has less cell calculated. Otherwise, Moore scheme has bad performance, since it has 4 of 29 ill structure cases of its transition rules. To improve the performance of von Neumann scheme, we can extend its radius into 2 units. Extended von Neumann scheme also gives maximum performance in 2 of 29 cases or pairs of transition rules. It has the ideal property of transition rule, which has explored.

According to random number generator applied, the model with uniform continues distribution is better than the model applies random discrete distribution or normal distribution. It has proven for simple von Neumann scheme with normal resolution maps. Whilst manipulation of maps resolution is a contra productive effort, since it can reduce the quality of transition rules.

VII. FUTURE RESEARCH DIRECTION

Furthermore to improve the performance of transition rules using regression analysis, we can conduct advance research with focus on alternative model of regression, include non linear model. We will follow up it by exploring 3 alternatives model, i.e. pure quadratic model, intersection model and quadratic with intersection model. Linear model is the special case of pure quadratic model, without quadratic coefficient. In this case, we should apply extended von Neumann scheme, since it has been proven as good scheme in this paper.

If we have found the best scheme and technique for exploring transition rules, we needn't to use all of them as dynamic engine, just pick up sub set of them as representation of all transition rules on the data was observed. The popular technique to extract it is clustering analysis, which's produces some centroids as the center of cluster formed. So we need to find best clustering technique, that appropriate for this case.

Finally, all of the effort described in this paper is a pre-processing and processing step of data mining, to find best scheme and parameter setting for the model. This phase should be continued with implementation and validation phase. This important phase will identify, whether the model effective for modeling spatiotemporal dynamic or not.

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Ahmad Zuhdi, Sarjana in Mathematics (Bandung Institute of Technology, 1986), MS in Computer Science (University of Indonesia, 1998), Doctor candidate in Computer Science (University of Indonesia), Lecturer and researcher employee at Trisakti University Indonesia. Email: zuhdi@trisakti.ac.id

Aniati Murni Arymurthy, Insinyur in Electrical Engineering (University of Indonesia), MS in Computer Science (Ohio State University), Doctor of Computer Science (University of Indonesia, 1997), Professor at Faculty of Computer Science University of Indonesia. Email: aniati@cs.ui.ac.id

Heru Suhartanto, Sarjana in Mathematics (University Indonesia, 1986), MS in Computer Science (University of Toronto, 1990), Ph.D in Parallel Computing (University of Queensland, 1998), Professor at Faculty of Computer Science University of Indonesia. Email: heru@cs.ui.ac.id

Maruli H.Manurung, Sarjana in Computer Science (University Indonesia, 1996), MS in Computer Science (University of Edinburg), Doctor in Computer Science (University of Edinburg), Lecturer and researcher employee at Faculty of Computer Science University of Indonesia. Email: ruli@cs.ui.ac.id