World Applied Sciences Journal 3 (Supple 1): 136-142, 2008
ISSN 1818-4952

Land Use Allocation Optimization Using Advanced Geographic Information Analyzes

[1]H. Rezayan and [2]A.H. Najian

[1]Depatment of Surveying and Geomatics Engineering, University of Tehran, Iran
[2]Department of Urban Planning, Faculty of Architecture and Urban Planning, Shahid Beheshti University, Tehran, Iran

Abstract: Space allocation of urban facilities is a critical field of decision making in urban planning. Supposing that Geographic Information (GI) provide us with more objective parameters for space allocation, Geographic Information Systems (GIS) is used by urban planners. But usage of GIS in urban planning is limited to simple analyses believing that complex spatial analyzes complicate the currently established approaches in urban planning. We propose that sticking to the basic rules of decision making in urban planning referring to the reality and providing the GI analyzes as syntactic sugar which complement decisions made by urban planners, enable us to use more complex GI analyzes. In this paper, we study the application of two complexes GI analyzes in urban space allocation. These analyzes are first population density surface generation using Pycnophylactic Estimation-Maximization (PEM) areal interpolation and second Adaptive Multiplicatively Weighted Voronoi Diagram (AMWVD) to derive service areas of urban facilities. The results show that these two GI analyzes optimize the urban planners' space allocation, while they do not suppress the established rules of urban planning. These analyzes are used to define the overpopulation level of primary schools estimating their current service area and comparing their estimated and expected level of service. The service areas of schools are estimated minimizing the proportional difference of the estimated and expected level of service, based on the population, proximity and safety of access rules that are used for space allocation of the primary schools. The minimization is carried out using linear and Simulated Annealing (SA) approaches. It is observed that linear optimization generates better results. This means that using the two complexes analyzes (PEM and AMWVD), the complexity of the space allocation of primary schools is not changed dramatically.

Key words: Adaptive Multiplicatively Weighted Voronoi Diagram (AMWVD) . Pycnophylactic Estimation Maximization (PEM) . service area . level of service . land use space allocation

INTRODUCTION

Land uses are the building blocks of the decision making process in the cities. Space allocation of land uses plays a key role in urban planning processes. These processes deal with a combination of physical and human related issues and try to balance them, targeting fulfillment of human needs and facilitating their activities. Human activities are closely related together. It induces complex interrelationships between land uses. Such interrelations compose the spatial structure of a city [1].

Undermining the mentioned complex interrelationships in decision making processes result in defective cities with malfunctioned services and dissatisfied citizens. It is all wasting of limited resources of cities and is counter-productive. This is what current methods of space allocation of urban facilities, especially in developing countries, are suffering from. These methods are subjective and based on the experimental knowledge of expert urban planners. The problem can be expressed in the way that many the first is the best decisions are made in cities.

Being subjective, it is difficult to evaluate the urban planning decisions. Geographic information (GI) and geographic information system (GIS) are used to improve the situation admitting more objective parameters into existent urban planning processes. But the GI analyzes used in urban planning are very simple usually limited to visualizing the study area, showing classified data, execute some queries and carrying out some measurements on the map like length and area measurement. It is supposed that application of more complexes GI analyzes will complicate and suppress the established urban planning decision making processes and create inexplicable results that contradict with experience of the experts!

Corresponding Author: H. Rezayan, Depatment of Surveying and Geomatics Engineering, University of Tehran, Iran

We propose that sticking to the basic rules of urban planning, referring to the reality and providing the GI analyzes as syntactic sugar which complement the established urban planning decision making processes, enable us to use more complex GI analyzes. In section 3 of this paper we studied two complexes GI analyzes:

- Pycnophylactic Estimation-Maximization (PEM) which is used to interpolate continuous population density surface.
- Adaptive Multiplicatively Weighted Voronoi Diagram (AMWVD) which is used to derive current service area of the urban facilities.
- We used these two GI analyzes to represent more realistic picture of quality of service of primary schools at the scale of urban districts. The goal is to define the overpopulation level of primary schools that is the main problem of primary schools especially in big cities like Tehran, resided in developing countries.

It is done by estimating the current service area of the schools and comparing their estimated and expected level of service. Level of service of a school is defined as the number of students in that school and the service area is the physical area which these students are coming from.

The current service areas of schools are estimated minimizing the proportional difference of the estimated and expected level of service, based on population, proximity and safety of access rules discussed in section 2. The minimization is carried out for a case study in Tehran, using linear and simulated annealing (SA) approaches. The results discussed in section 4 show that linear optimization generates better results than SA approach. This means that the complexity of the space allocation is not changed dramatically using the two complex analyzes (PEM and AMWVD).

The results derived from the two analyzes are implemented in this paper provide the urban planners with the gaps in level of services of facilities like primary schools. It is the main data deciding about locating new primary schools which is introduced as further work in section 5.

Primary schools space allocation process: The three main rules studied by urban planners for space allocation of primary schools are as follow:

- Population of the area to be planned,
- Safety of access for the children reaching from home to school and
- Proximity of home and schools.

The planner's goal is to allocate schools providing the highest level of service. The level of service for each school is calculated using Eq. (1)

$$LOSi = floor\_areai/Service\_per\_Capita \qquad (1)$$

Where, LOSi denotes level of service for i^{th} school and Service per Capita is the area required by a child in a school. According to the regulations of Iranian Ministry of Housing and Urban Development, is about 4 square meters [2].

A primary school should be placed in the walking distance of 400 to 800 meters from residential areas (4-5 minutes of walking), providing a safe access for its users (children aging 6 to 10) [2]. Safety of access entails that children do not cross any major or minor arterial road in order to reach their school.

Applying these three rules, planners create 400 and 800 meters circular buffers for existing primary schools. The population is estimated visually based on density of buildings and using the classified maps of census districts. Safety of access is checked visually by highlighting the arterial roads and forming road districts which are bounded by these roads. The areas cut by these roads are added visually to the service area of the schools. Then the areas where not resided in these buffers considered as gaps. The process is continued by locating new schools in the gap areas.

The major drawbacks of the mentioned process are:

- The population density estimation is done poorly. It is due to the inconsistency of census districts boundaries with road districts and municipal districts. Besides, the classified maps of census districts suppose that the population is distributed homogenously in each census district. Also the crispness of population distribution at the boundary of census districts hinders the visual analyses and possible topological analyzes (deriving contours and population segregation boundaries) in future.
- Rigidity of circular buffer areas results in large amount of overlaps which contradicts the reality in which each child will go to just one primary school. These overlaps are sometimes justified as representing a level of arbitrary selection between alternative schools. Although this justification is correct, but ability to have alternatives is more mental than physical. The service area of schools are nested rather than overlapped. Providing alternative schools physically will result in wasting the limited resources of cities, especially in developing countries.

- The mentioned rigidity of circular buffers also hinders application of safety of access rule, as the circular boundary hardly match the irregular boundaries of roads districts.

MATERIALS AND METHODS

Among the three rules described in the previous section, the safety of access rule is hard coded. We adopt this rule introducing road district as an area bounded by roads which endanger child's access to the schools.

In regards with the population rule, an areal interpolation [3] should be used to estimate the population data missed due to aggregation done in census districts. We propose Pycnophylactic Estimation-Maximization (PEM) areal interpolation approach. It is a combination of Estimation-Maximization (EM) method [4], which is a statistical maximum-likelihood estimator and Pycnophylactic condition [5], which says that people prefer to live near each other. Similar to the current approach used by urban planners, we used residential land use data to guide the PEM. It means that the interpolation will be limited to residential areas. The result will be a continuous population density surface estimate more realistic distribution of people. This continuous surface can be combined with different partitioning of space like roads districts.

PEM is done as follow:

- Estimation of all census districts population using Eq. (2).

$$Q(\theta \mid \theta^{(k)}) = E[\log L_c(\theta) \mid y, \theta^{(k)}] \tag{2}$$

Where, k denotes the k^{th} iteration, $L_c(\theta) = f(x|\theta)$ is the likelihood of estimated population to the complete population,

$y = (y_1, y_2, \ldots y_n)'$ is the observed population,
$x = (x_1, x_2, \ldots x_n)'$ is the complete population,
θ is a hidden vector of variables that represents the missing data and
4 is the expected value of the log-likelihood.

- Maximization of θ using $\theta^{(k+1)} = \underset{\theta \in \Theta}{\arg\max} Q(\theta \mid \theta^{(k)})$
- Stabilization of the population in each census district using Eq. (3).

$$\iint z(x,y)\, d_x d_y = P_i \tag{3}$$

Where z (x, y) the population is surface and P_i is the total population of the ith district. Eq. (3) in discrete space is represented in Eq. (4).

$$\sum_x \sum_y z(x,y) = P_i \tag{4}$$

Smoothing the crisp boundary of census districts and generating continuous borders by minimizing Eq. (5).

$$\iint [(\partial z / \partial x)^2 + (\partial z / \partial y)^2]^2 d_x d_y \tag{5}$$

In discrete space we have Eq. (6) and Eq. (7):

$$\frac{\partial^2 z}{\partial x^2} = (z_{i,j+1} - 2z_{i,j} + z_{i,j}) / \Delta x^2 \tag{6}$$

$$\frac{\partial^2 z}{\partial y^2} = (z_{i-1,j} - 2z_{i,j} + z_{i+,j}) / \Delta y^2 \tag{7}$$

Then Eq.2 is implemented as convolution of a 3*3 mask with population data.

- Application of pycnophylactic condition, which is done by convolving a 3*3 averaging mask on population data.
- These steps are iterated until the condition of $L_c(\theta^{(k+1)}\text{-}L_c(\theta^{(k)}))<\varepsilon$ is satisfied. At first iteration the population is considered homogenous over the residential areas.

We suggest Adaptive Multiplicatively Weighted Voronoi Diagram (AMWVD) [6] to deal with the proximity rule. It is like inverse solution of weighted voronoi diagram as it tries to allocate space satisfying a predefined ratio of area to weight. The AMWVD is somehow similar to cartograms, but the centers (primary schools) do not move using AMWVD. We minimize the proportional difference of defined and calculated level of services of schools, as shown in Eq. (8):

$$\Delta = \frac{1}{N} \sum \frac{|\text{expected\_LOS - estimated\_LOS}|}{\text{total\_population}} \tag{8}$$

Where N is the number of schools and
LOS denotes the level of service

The following distance function is offered:

$$d_{i,j} = \frac{\text{euclidean\_dist}(p_i,\text{school}_j)}{W_j} \times \text{population\_slope}(p_i,\text{school}_j) \quad (9)$$

Where euclidean_dist(pi,schoolj) is the Euclidean distance of ith point and jth school
W is the vector that defines direction of the optimization for each school.

The proportions of coordinates of W represent the proportion of level of services of schools (Eq. 10):

$$LOSi/LOSj = Wi/Wj \quad (10)$$

In Eq. (9), population slope admits (Eq. (10)) the effect of population into the AMWVD:

$$\text{population\_slope}(p_i,\text{school}_j) = \frac{\text{euclidean\_dist}(p_i,\text{school}_j)}{\text{population}_i} \quad (11)$$

Where population_i is population at i^{th} point derived from the created population surface using PEM.

Population slope enable us to consider the effect of vacant areas without removing these areas before using the AMWVD. Removal of vacant areas before analyze uglifies the results visual representation, which is considered important for urban planners. These areas can be removed after analyze on demand of the user without repeating the process.

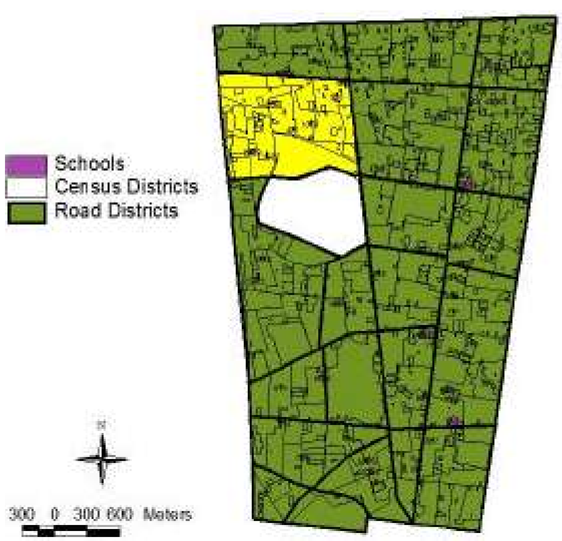


Fig. 1: The studied road district is highlighted at top-left. The area of this district is about 114 hectare. There are also some vacant areas in this road district

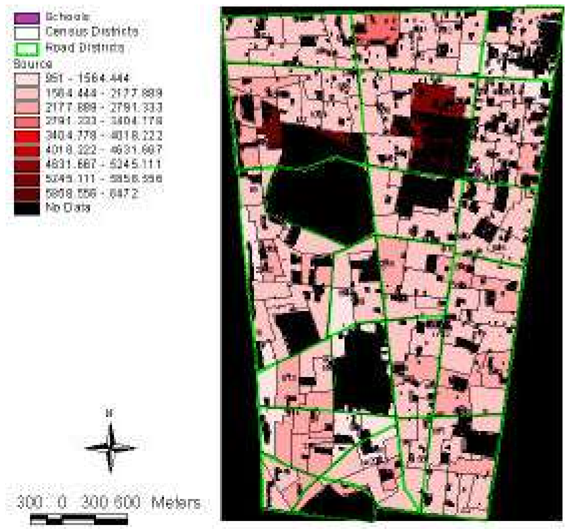


Fig. 2: Population distribution of census districts before using PEM

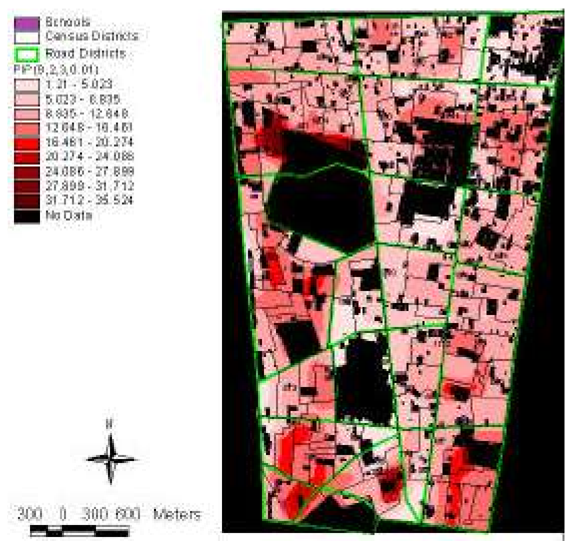
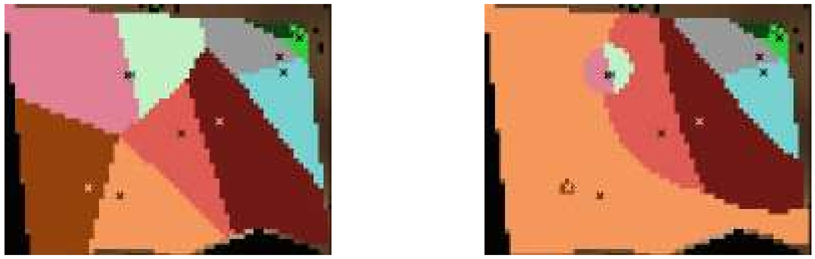


Fig. 3: Population distribution of census districts after using PEM

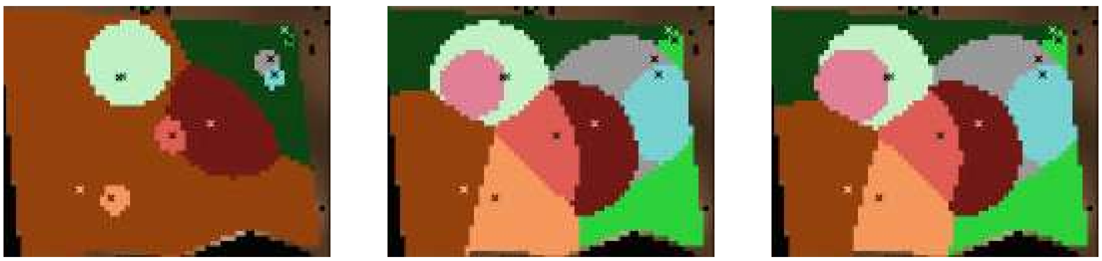
Figure 5a, 5b and 5c show the result of AMWVD using a linear optimization after 0, 50 and 100 iterations where $w_i+1 - w_i(1+\Delta\times\alpha)$ with $\alpha = 0.7$. Figure 6 illustrates optimization plot of this process.

Case study: The proposed methodology is implemented in a cellular discrete space for a road district resides in municipal district no. 11 of Tehran. Figure 1 represents the scope of the studied road district. Here we used Tehran 1:2000 cover map data, updated in 2006 by Tehran GIS Center and census data derived from demography carried out in 2007 by Statistical Centre of Iran.



(a) (b)

Fig. 4: Simple Voronoi diagram of schools in the study area (a) without considering the population data and (b) with population data. The result show that Simple Voronoi diagram can not handle population data



(a) (b) (c)

Fig. 5: Linear optimization of AMWVD: (a) after 0 step, (b) after 50 steps, (c) after 100 steps

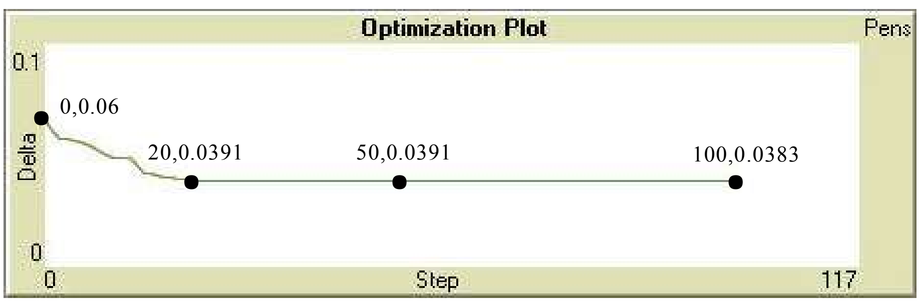


Fig. 6: Optimization plot of linear optimization of AMWVD.The model converges after 20 iterations

(a) (b) (c)

Fig. 7: Simulated Annealing optimization of AMWVD after (a) 0 step, (b) 50 steps and (c) 100 steps

Figure 2 and 3 show the population density of the study area before and after using PEM. The convergence limit 0.01 of the PEM is met after 9 iterations.

For each census district the population density is defined homogeneously dividing the total population by area of the district where the land use is not vacant. The result shows crisp edges at boundary of the census districts.

The convergence limit is 0.01. The model converged after 9 iterations. The black areas represent vacant regions which are defined by land use data and entered into the model as a control layer.

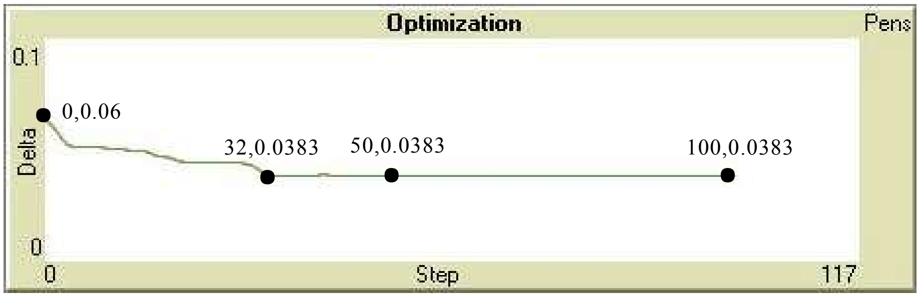


Fig. 8: Optimization plot of simulated annealing optimization of AMWVD. The model converges after 32 iterations

Fig. 9: Simulated Annealing optimization of AMWVD

Figure 4a and 4b show service areas of the schools reside in the selected road district, using simple Voronoi diagram, toggling the population on and off.

Similarly, Fig. 7a, 7b and 7c show the result of AMWVD using simulated annealing (SA) optimization after 0, 50 and 100 iterations where $w_{i+1} - w_i(1+\Delta\times random(1))$. Temperature schedule is $T = \beta T_0$ with $\beta = 0.7$ and the energy distribution probability function is $P = e^{-\Delta/T}$ (Boltzmann probability distribution function). Figure 8 shows the optimization plot of using SA.

CONCLUSIONS

The results presented in the previous section (Fig. 4a and 4b) show that the simple voronoi diagram is not useful for this application. It also became worse when population entered into the process.

Linear optimization represents better results than simulated annealing optimization. While they both converge to 0.0383 after 100 iterations, the linear optimization converge faster at 20 steps. It means the proposed approach is less complex than what it seems and it can be justified more easily and fits more effectively into current process of space allocation.

Figure 9 shows quality of services of the schools. It ranges from 0.0326 (darker) to 0.0426 (brighter). Then, all of the schools have 3% to 4% overpopulation.

Using simple Voronoi diagram, this quality ranges from 0.01 to 0.18. It means a 1 to 18% of overpopulation which ranges up to 17 points. This contradicts the real situation.

One of the benefits of using AMWVD is its ability to generate island areas. While each location is assigned to just one school, we can find schools that their service areas are embedded into another school. It brings about a mental sense of overlapping which interprets people's choice between alternative schools in reality.

The results showed that complex GI analyzes can be used in decision making processes (like what is in practice with land use planning) if these analyzes are manifested as complements to the experts knowledge and experience. We should stick to the accepted rules of urban planning and try to improve each rule separately to create more realistic results. The quality of services of schools shown in Fig. 9 defines the gaps in services. It is the fundamental data for location of new primary schools which is our further work [5, 6].

ACKNOWLEDGEMENTS

The support of Dr. Bahram Aminzadeh is gratefully acknowledged. We also appreciate cooperation of Part Consultant Engineers (http://www.partco.ir), which is in charge of creating the master plan of our study area, for providing the land use, roads and census data.

We acknowledge developers of NetLogo 3.1.2 (http://ccl.northwestern.edu/netlogo), which is used to implement the methodology of this paper [7]. We also used Arcview GIS 3.2a for data preparation.

REFERENCES

1. Alexander, C., 1965. A City is Not a Tree. Architectural Forum, 1 (122): 58-62.
2. Habibi, M. and S. Masaeli, 1999. Urban Land use per Capita's. Ministry of Housing and Urban Development, National Land and Housing Organization (In Persian).

3. Gregory, I.N., 2002. The Accuracy of Areal Interpolation Techniques: Standardizing 19th and 20th Century Census Data to Allow Long-term Comparisons, Computers. Environment and Urban Systems, 6(19): 293-314.
4. Dellaert, F., 2002. The Expectation Maximization Algorithm. College of Computing, Georgia Institute of Technology, GIT-GVU-02-20.
5. Tobler, W., 1979. Smooth Pycnophlactic Interpolation for Geographical Region. Journal of the American Statistical Association, 74: 519-530.
6. Reitsma, R., S. Trubin and E. Mortensen, 2007. Weight-proportional Space Partitioning Using Adaptive Voronoi Diagrams. Geoinformatica, 11: 383-405.
7. Wilensky, U., 1999. NetLogo. Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL.