45th European Congress of the European Regional Science Association
Land Use and Water Management in a Sustainable Network Society
23-27 August 2005, Amsterdam, The Netherlands

Computerised Applications and Evaluation Methods in Land Zoning

Cihan Ahmet Tutluoğlu*
Vedia Dökmeci**

**Bilgi University, Istanbul, Turkey*
***Istanbul Technical University,Istanbul,Turkey*
catutluoglu@bilgi.edu.tr

Abstract

Land zoning is an important issue in urban & regional planning, requiring heavy computational burden. Another challenge is having to decide on the parameters to be used in the evaluation. This paper takes the transportation-communication frequency and the rent-inflator interactions between different zone types (with possible coefficients) as the major elements in zone-evaluation. For the type of evaluation on the other hand three alternative methods were used. One of these methods only considers one-way interactions in rent-inflator relations. Another one is developed to include a self-updating mechanism on the same interactions. The third of the methods meanwhile attempts to take in account the topological factors. Software was developed in C++ that uses the Manhattan Metric to calculate the distances. The program prompts the user to feed in the evaluation method, different interaction coefficients as well as different land types and different maps. The software, based on the preference can either use a steepest descent heuristic or an enumeration algorithm.

Introduction

Land Zoning and Rezoning is an important issue that concerns the usage of land in an optimal way.

We know that the demand for new land areas to be used, generated by ever-growing population in the developing world is not usually satisfied in an efficient way.

The problem lies in the fact that areas that can be opened up to be used are limited. For every area to be zoned, a pre-study of the location, provision of infrastructure and other needs is needed. Besides this, it is not hard to imagine that the total amount of land area that can be used is limited, since the land area in the world has its limits. Although landfill alternatives, albeit available at high costs, may provide for the relaxation of this latter constraint, one should notice that even this cannot go beyond a level. Moreover, the necessity to leave certain areas for recreational use, necessity to allocate land for future purposes also crops up from the already restrained land area.

It also is tempting to consider that since once a zone is established in an area, it is very hard to rezone it, as gentrification projects and the changes over the course of land zoning in a city show. As the demand structure in a place changes, it may not be as easy for a specific layout of zones to adapt to it, as the previous owners would try to keep their privileges or try to refrain from the high costs of moving. This type of a mismatch, in turn, would create an opportunity for rent seekers who would try to find the potentials in places and take part in their redistribution. However, this would imply that there would be a loss of time in between as well as the redemption of the costs of zoning the land, building and rebuilding of due infrastructure and hence bring about huge tangible and opportunity costs to the society as well as to the governments that try to collect as much tax as possible from them.

The role of the urban planner hence emerges to coordinate among various interlinks between different land use patterns in a place so as to derive the maximum gain from exploitation of their specific needs and minimise due losses.

Therefore one is required to find a way to optimal way to place different types of land into a given network.

From the most intuitive tenets of operations research, one is tempted to find the most efficient or optimal way to allocate limited resources. Therefore, the answer was sought for through this field.

The crucial parts in such a definition stick out on defining the constraints, the objective function and more important than anything else, variables.

When it comes to modelling social programmes or issues concerning public spending, the objective function is usually a combination of double aims, one being maximisation of public utility and the other being maximisation of profits.

The earliest well-known contribution was formulated by Kuhn-Tucker(1951). However, applying the techniques mainly soared in the 70's. Dokmeci (1974), Barber (1976) developed models that indeed tried to find a midway between conflicting objectives such as minimising energy consumption and increasing ease of transportation. The technique for optimal placement of activities in zones (TOPAZ), which offers a constrained optimisation of multiple goals (Brotchie, 1980), was widely used in the 80's, with a precursory application in Teheran, which, according to Chadwick, 1987, maximised total net establishment and transportation benefits and thus increased the aggregate of individual net perceived gains. Wilson (1981), applied the conventional aggregate land use and transportation interaction models within multiple-objective framework to estimate behavioural responses. Gilbert (1985), on the other hand, developed a model based on single land use which tried to incorporate different interaction factors.

Although different methods such as pre-emption and minimisation of the deviations from optimum may have also been used, in order to refrain from heavy computational burden and to allow for the user to define relative importance of different goals, assinment of different weights to each of the goals will be exploited through our study.

In our case, the public utility that can be driven from a certain parcelling alternative may perhaps be the best reflected in transportation, as also argued by Barber (1976), Black and Kuranami 1983 and Chadwick 1987). Simply due to a probable layout alternative, it may be seen that the average time spent on the roads may be eased, which is a stress cap for the people who use the system.

Another aspect of efficiency, which was cited by Ratcliff in1948, is the ability of the system to generate rent, since desirability is best reflected in the rent values. Therefore, as for the profit obtained from allocation, the rent value the lot generated due to the specific assignment may be used.

Alonso (1964) tried, in this respect, to define the value of a site as a function of distance from the central business district, making an analogy to Löschian and Von-Thünen principles. Brigham (1965), on the other hand, has emphasised the importance of surrounding sites, whether they are residential etc., on the actual rent value of the sites. Hammer (1974), has also made a similar remark when he analysed the property sales in the vicinity of Pennypack Park and has seen that proximity to the park did cause an increase in the rent value. Coughlin (1971), provides an example where a positive effect of business areas on the surrounding may be traced. Ridker and Henning (1971), on the other hand have shown that industrial sites may have negative effects on different land types.

So, making an area somewhat more appealing to industrial location and trying to allocate residential sites there would simply hamper the value of the residential blocks and obstacle a potential of high tax revenues that could have been driven out from the industrial lots there. This bar on the rent value would not only reduce public revenues and duly allow for larger investment into the area but also imply a greater utility driven from the place, since no one would be paying more for a place if they are not getting anymore utility from it.

Therefore, as will be explained in the methodology part, although many alternative methods may be debated upon, for all practical purposes, the objective function was thought of to be a combination of the rent and the transportation values.

Our set of constraints on the other hand will basically be the limits of the map, that is, the area where assignment of the lots may be deemed feasible, which in turn implies that the area in question should be free (no lot already assigned there) and be open to land use. Moreover, it is assumed that the lots have a limited number of types to be assigned to. Although the types are predetermined by the user, hence subject to arbitrary modification, no continuous function of unlimited alternatives applies to our assignment scheme.

The basic set of variables on the other hand happens to be which type is assigned to which lot in the map. This is to say that the programme is able to jump through one objective value to another only through changing the lot types and nothing else.

Although this overall scheme is valid throughout our programming alternatives, it is in the very interpretation and in the application of different parameters that a variety is reached.

For example, again in the models, the possibility of allowing for different topographical types and choosing to have recursive definitions on the rent value or choosing this or that type of a method to calculate the distance provides us with a variety of alternatives to decide upon.

It should be noted that among the purposes of this study, to show how the very definition of a specific objective may cause the result to change; how different visions of the same problem may apply, what these results could mean and how they can be exploited prevail, as well as to show that making use of computers is always possible.

Methodology

In the opening menu, the user may choose what type of method to use. Following up on the course, the user may readjust the distribution of various land types in the given map as well as the extents of the map.

The user is allowed to extend the list of land types or readjust the values for the correlation or the transportation matrices of the land types.

The user may as well wish to stabilise some parcels on the map before trying to find an optimum layout for the list of additional parcels to be placed. The user is then prompted to give how many parcels of what type are to be laid down on the map.

The basic method for evaluating the different layouts is done through the following scheme:

As mentioned before, the value of a parcel is assumed to be consisting of a rent value and a value for the ease of transportation, as was done by Dokmeci, 1993.

The rent value of a parcel is thought to be adjusted following the layout of neighbouring cells. To this end, a matrix of rent multipliers for various parcel types is generated, in which for every type of a parcel, the net effect it exerts on different parcel types is written. The matrix gives us an added value that for example an industrial complex could bring about on a neighbouring commercial site, may it be a negative or a positive one. All these effects caused by individual parcel types are assumed to overlap and accumulate to give a total rent value for the cell.

However it may be a challenge to find out to what level of proximity a parcel could go on affecting the neighbouring ones. Therefore we have devised the following alternatives for this problem.

Following the mentioned study, the first method assumes that only neighbouring cells could affect the rent value of a parcel. This implies that only the parcel multipliers that have their centroids in a distance of one unit on the Cartesian Matrix can add up on to the value of rent. This would imply checking the parcels one cell up, one cell down, one cell to the left and one cell to the right if the Manhattan Metric is to be used. A similar cap may be assumed for different distance levels, that is for example assuming that beyond a distance of 200 meters, parcels no longer are effective one on another.

The second method on the other hand assumes the gravitational hypothesis laid down by Reilly, which is to imply that, the rent multiplier of a certain parcel type on another drops down inversely proportional to the square of the distance in between. In this case, all of the cells on the matrix are assumed to be affecting each other, having a coefficient given in the relations matrix that drops down exponentially as the distance in between increases.

However, it may be argued that indeed a parcel affects its neighbours proportional to the original rent value that it has. That is to say, that if we are to build in an residential block in a neighbourhood where the rent multipliers are traditionally set high, for example among some condomia of a high value, then the value of the site would be higher than, say, when placed in another site without any prior rent bias. To cope with that thesis, the user is asked to specify number of recursive loops on which to define the rent value of a place. Each loop recurs as follows: every cell starts with an initial rent value (of 1, for the first loop). Then, for every parcel on the map, the parcel value is multiplied by the rent multiplier in between the two parcels and divided through the square of the distance in between, following up on the gravitational pull hypothesis. Adding all these values up, a new value set for parcels is accomplished on updating the rent values for the cells. In the following loop, the same algorithm is re-run, this time taking the newly calculated values as the initial values. The basic axiom that lies behind the method is that the values of already existing parcels or the layout of different parcels actually happens to take on a value based on the other cells that exist on the map. Therefore, the increase in the rent value of one parcel will be reflected on the others in the long run. Each time the loop is cast, the current layout of the rent matrices are used in updating the rent values of individual cells. The more the number of turns is set to be, the more true to the mentioned hypothesis the model will get to be. However, each loop increases the computational burden by sizable amounts.

The total rent value in the system, on the other hand is assumed to be the addition of all the individual rent values in the network, no matter which way the computation of the rent values are done.

As it can be guessed, the optimisation problem includes the maximisation of this total rent value of the system.

The other determinant of the value of a cell is thought of to be the ease of transportation at the given location.

Following on the work of Dokmeci (1993), it is thought that between each parcel on the map, there will be a flow, based on the types of the parcels. For example, every commercial site will have an expected level of flow with the residential sites. The level of expected flows, are registered in a transportation matrix. The basic assumption, that may be challenged, is that the effect of distance on the commuters has a linear function. Therefore, for each pair of parcels, the level of flow is multiplied by the distance in between. All these effects, in turn, are summed up to find the total level of undesirability in the current transportation scheme.

The distances are calculated either using the Manhattan Metric (or rectilinear-rectangular distances as alternatively known), that is the sum of the difference in the y and x axis values, or through taking the square root of the sum of the squared distances of the coordinate values.

The optimisation of the layout requires the minimisation of the level of undesirability of the transportation scheme.

As can be seen, the model requires a goal programming approach to evaluate the optimal level for the two goals. In order to ease the problem, the method of calculating the weighted average of the goals is followed (where a linear combination of the goals is assumed for the incorporation of the weights). The weights for each of the goals on the other hand are the normalised values of the weights that the user is assumed to give. The optimisation model can be found in the appendix.

For the solution of the problem, the user is asked to specify the most desirable out of a set of options.

The first method is to use the enumeration algorithm. In this scheme, starting with an initial layout, all possible alternatives are evaluated one by one (the last parcel in the series in moved a cell forward or downward and taken to the start when it is the penultimate one’s turn to be moved. The method is pursued until when all alternatives are exhausted). The network that offers the most optimal layout is given as the answer.

An alternative method is to use a variation of the famous (Computerized Relative Allocation of Facilities Technique) algorithm. CRAFT algorithm, as is known, is developed so as to help in layout planning for facilities. Through this algorithm a basic layout is generated through either random assignment or through a likelihood assignment heuristic and the total value of the objective function is calculated. From that point onwards, pair-wise interchanges are evaluated within acceptable boundaries of the system and based on the exchange heuristic, a swap in the current network is done until when a reasonable solution is reached.

On trying to apply the CRAFT algorithm, we take each of the parcels as facilities and create dummy parcels for empty cells. In order to have the initial allocation, we at first calculate an expected value for each of the parcels to be assigned (by assuming that all parcels are somewhat allocated at a distance of 1 to each other). We then start by putting the parcel with the highest expected value randomly on the map (or closer to the existing parcel with highest positive relation). Then at each step we find the existing parcel that has the highest positive relation with the cell to be assigned (which simply is the parcel which has the highest expected value – if it has all its neighbourhoods occupied, the next one is chosen). We try to do the assignment so as to have the maximum number of neighbours in the new solution set. If there is a tie, the new parcel is placed in either place starting from the left in a clockwise manner.

Having done the initial assignment, in our first alternative, we have formulated our code so as to evaluate all pair-wise exchanges within a neighbourhood of 1 of the whole network of allocated parcels, between parcels of different types (whereas in an alternative setting we have only considered the changes between neighbouring parcels only-as suggested by the original CRAFT algorithm). At each step, the unique exchange of the cells in question and the gain this would bring about is chosen. Then, the exchange that provides the highest net change is effectuated.

The Original Problem

Our original problem of interest was to find the optimal way to allocate 3 residential, 1 commercial and 1 recreational parcel in an area to encompass 64 (8x8) parcels on which, in the centre are located 2 parcel-wide lake and an industrial parcel that is at a parcels' distance to the north of the lake.

The very core of the problem involved the application of the first of the three evaluation methods, in which the distances are to be taken as Manhattan Metric, with the weights given as 60% for the rent and 40% for the transportation. The rent-matrix and the transportation matrix for the problem were given on Table 1 and Table2.

	Lake	**Residential**	**Commercial**	**Recreational**	**Industrial**
Lake	0	0	0	0	0
Residential	0	2	8	6	10
Commercial	0	8	0	5	0
Recreational	0	6	5	0	0
Industrial	0	10	0	0	0

Table1: The Interaction –Transportation Matrix

	Lake	**Residential**	**Commercial**	**Recreational**	**Industrial**
Lake	0	0	0	0	0
Residential	10	5	10	10	-7
Commercial	0	10	10	5	0
Recreational	10	10	5	0	-10
Industrial	10	10	5	5	10

Table2: The Value Impact - Rent Matrix

Notice that from these tables, we may understand that the placing of a re

The enumeration algorithm reached the following solution on figure1 in 60.25 minutes on a 1000MHz PentiumIII processor with 128 MB RAM memory.

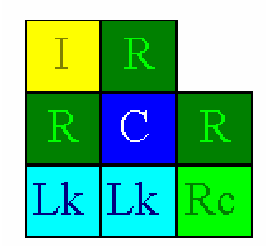

Figure1

Notice that I stands for the industrial lot whereas R stands for the Residential, C for the commercial and Rc for the recreational lots. Lk on the other hand represents the lake.

The heuristic algorithm on the other hand proposed the same outcome, which was reached in less than 5 seconds. The algorithm indeed started with a good enough solution and reached the global optimum only through one exchange, between the recreational and commercial spots.

The second evaluation mechanism which involved considering the effect of non-adjacent parcels on the other parcels (following up on the assumption that they have an effect inversely proportional to the distance in between), gave the results on figure2 in 81.41 minutes on the same computer.

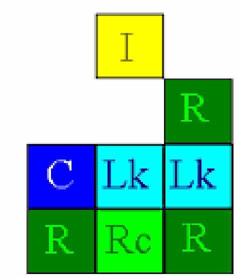

Figure2

This result is understandable since unlike in the previous model where the industry could only affect its immediate surrounding, in this framework, the industrial complex has its effects widened to the whole matrix, which is the reason why it is secluded from the rest of the parcels.

The method of using recursive loops to determine the values on the other hand yielded, oddly enough, the same layout as when the method of taking the effect of further parcels was used (when the loop was cast only twice).

However, to see what would happen when the original scheme was slightly altered to allow for the effect of different road multipliers (which could just as well imply the effect of different infrastructures), we have decided to include two areas of an improved infrastructure- which we called as the “road”- into the model, one being right next to the lake and the other being right on the parcel above it. We have taken the impedance effect of this new structure on transportation as half of the others.

It turned out that the solution in this case happened to be the same as in the previous model. However, when the impedance effect of the roads was further dropped down, it was observed that the recreational and commercial sites were swapped.

However, the actual difference in this model is not confined to the difference in layouts only. It is striking to see that the model, when this scheme was applied, despite the fact that it did not change the layout decision, offered a value of -278, which, when compared with -344, the value obtained without any such differentiation in topology, implied a 66 increase in utility or welfare, however these may be interpreted.

Conclusions

The programme is efficient in proposing optimal solutions quite fast. CRAFT algorithm, in its own complexion offers an even faster tool to reach the solutions.

However, it should well be noted that the solutions and the speed to reach them is very much contingent on the initial assumptions.

The method of using recursive definitions on the landscape stands out as the one that causes the highest computational burden. This in turn is followed by the models where the rent multipliers are calculated over the whole spectrum of available lands, instead of simply taking the effect of neighbouring cells. In either case, taking Euclidean distances instead of using the Manhattan Metric changes the computational requirements if not the memory allocation on the computer.

The application of the Heuristic tremendously reduces the amount of time required and the heuristic proved to be efficient in coming up with the correct solution. However, it should well be noted that the CRAFT Algorithm indeed is a local search heuristic. This means that the odds that it will simply be stuck at a certain interval are quite high. However, it has been proven that the worst case scenario analysis for CRAFT remains lower than the algorithm developed by Dokmeci (1993), which may be considered as of being good enough.

The programmes also stand out in that they offer for a room for policy analysis. It has been seen that placing two unit squares of infrastructure into the domain may help in improving the overall value by sizable amounts. Therefore, through a certain normalisation of parameter values, we may manage to see whether a certain investment in the infrastructure can be deemed worthy or not. If the costs of building the infrastructure lie below the overall change in utility for example, funds may be raised to build that infrastructure there, knowing that it has its dividends in return.

The models may further be enhanced by adding in new definitions for landtypes and increasing the number of objectives. Moreover, the assumption that the method of transportation is unique can be relaxed.

However, we believe that our program may be useful in improving on the foundations for such research.

Appendix:

the Model:

$$Objective: \quad \max \quad \alpha \cdot V - \beta \cdot T$$

$$T_1 = \sum_n \sum_m \sum_j \sum_i \left[t_{(y_{ij}, y_{mn})} \cdot (|i-m| + |j-n|) \right]$$

$$T_2 = \sum_n \sum_m \sum_j \sum_i \left[t_{(y_{ij}, y_{mn})} \cdot \sqrt{(i-m)^2 + (j-n)^2} \right]$$

$$T_3 = \sum_n \sum_m \sum_j \sum_i \left[t_{(y_{ij}, y_{mn})} \cdot (|i-m| + |j-n|) \cdot (\frac{n_{ij} + n_{mn}}{2}) \right]$$

$$V_1 = \sum_i \sum_j \sum_{b=-1}^{1} \sum_{\substack{a=-1 \\ a \neq b}}^{1} \left[v_{(y_{ij}, y_{i+a, j+b})} \right]$$

$$V_2 = \sum_n \sum_m \sum_j \sum_i \left[v_{(y_{ij}, y_{mn})} \cdot \frac{1}{(i-m)^2 + (j-n)^2} \right]$$

$s.t.$

$$y_{ij} = x \ldots \exists x$$

$$\sum_i \sum_j \sum_{y_{ij} = s_m} 1 = g_m$$

$$y_{ij} \in S$$

The objective is to obtain a linear combination of either of the T values and V values at each step.

Indices

i,m **:** x-axis values

j,n **:** y-axis values

a,b **:** dummy indices to mark the neighbourhoods of the specific coordinates

Parameters

$\mathbf{t_{s1,s2}}$ **:** The frequency of transportation between the parcel types i and j

$\mathbf{v_{s1,s2}}$ **:** The rent inflator relation of parcel types i on parcel type j

$\mathbf{n_{ij}}$ **:** The ease of transportation at coordinates i and j

$\mathbf{g_m}$ **:** Number of nodes of type s_m to be assigned

x **:** The fixed nodes on the map

$\mathbf{s_m}$ **:** The elements of S

S **:** The set of all node types

Variables

$\mathbf{y_{ij}}$ **:** The type of the parcel at coordinates i and j

T1 **:** The first alternative for the evaluation of transportation in which rectilinear distances are used

T2 **:** The second alternative for the evaluation of transportation in which Euclidean distances are used

T3 **:** The third alternative for the evaluation of transportation in which the ease of transportation on each parcel is taken in account, where rectilinear distances are used

V1 **:** The first alternative for the evaluation of rent inflator relations in which only the effects caused by neighbouring cells are evaluated.

V2 **:** The second alternative for the evaluation of rent inflator relations in which all the effects caused within the boundaries of the map are evaluated, with an inverse squared decay.

References:

Dokmeci,V., G. Cagdas, S.Tokcan "Multi-objective Land-use planning," J. of Urban Planning and Developmen t,1993, 119, 1,34-46.

Barber, G. , "Land use planning via interactive multi-objective programming",1976, Envir. and Plng. A, 8

Zeleny, M., Multiple Criteria Decision Making, 1976, Springer Verlag, Berlin

Dr. M Khoshnevisan, Computaional Technique of Optimal Process-focused Systems , 2001

http://www.me.utexas.edu/~jensen/ORMM/omie/computation/unit/lay_add

Rossiter G., Lecture Notes: "Land Evaluation", 1994, Cornell University

Koroupolu, M., Plaxton, C., Analysis of a Local Search Heuristic for Facility Location Problems, 2000

*Tutluoglu, C., Altınel, K.,"Optimal Dealer Network for Private Cars for the Mercedes Benz Turk Co.", 2003 –not publish*ed