

THE "ALLOT" MODEL: A PC-BASED APPROACH TO DEMAND DISTRIBUTION FOR SITING AND PLANNING

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INTRODUCTION

This paper reports on development and application of ALLOT; a user-friendly, flexible computer model which has been designed to help governmental jurisdictions and private landowners throughout the world to achieve more economically efficient and environmentally sound land use and development patterns in a short period of time. ALLOT has the potential to drastically change the way that land use planning is conducted, since it has the capability to allow the incorporation of a wide variety of previously ignored environmental characteristics and up-to-date land use patterns.

ALLOT, which is written in the SAS programming language, contains two major parts. The first part employs a GIS database to conduct land suitability analysis for the area. It then produces maps showing the most suitable areas for various land use types. The second part appears to be unique in the field of computerized land use planning models. It combines the results of the suitability analysis with forecasted demand for various land use types to produce "optimum" future land use patterns. The model is capable of quickly analyzing a wide variety of forecasts, allowing easy comparison of different growth scenarios; and it can also be modified to reflect community goals and objectives, such as protection of wildlife habitat or attraction of industry. This flexibility, combined with the fact that it runs on any IBM-compatible PC (286 or higher), make it a powerful land use planning tool.

The model has been successfully applied in two "real world" situations. First, three alternative future land use patterns were developed for a 105,000-acre rural lakeside area. The area had rural characteristics and was lacking infrastructure, but a large influx of people was expected as the lake was filled (1).

The success of this effort led to a decision to test its use as a method for facility siting (using

landfill siting as an example). The siting was also done without sacrificing optimum utilization of the land; this was achieved by involving future demand for all land use types in the calculations (2).

This paper documents the ALLOT model's structure and workings, using the two applications described above as examples.

STEP ONE: LAND SUITABILITY ANALYSIS

Determining the best use for land is a complex process, because numerous factors (such as slope, soil type, and nearby land use) must be taken into consideration. In the marketplace, this determination is largely based on economic factors such as the price of the land, the potential return on investment, and the development cost. Unfortunately, the marketplace does not reflect the complete costs and benefits of development (3).

One arena where the market cost is woefully inadequate is that of environmental impacts (4). For example, the flat land of a floodplain may appear very attractive for intense residential development from an economic point of view. The real cost of developing this land, however, is very high; the cost of downstream flooding caused by the development is not paid by the developer or the residents, nor is the recreational value of lost wildlife habitat, the aesthetic value of the floodplain's open space, or even the cost of damage to homes in floodplains (in the USA this cost is borne by the taxpayers as a whole, through the federal flood hazard insurance program).

Even in the economic arena, the market system falls far short of perfection. For example, the price considered by a developer when deciding on land use will not include costs borne by the public for infrastructure, if it appears that the development will necessitate installation of a water line, a highway widening, or some other major tax-funded investment. These are just two examples of many thousands which could be given to illustrate the imperfections of relying solely on the private market economy to determine "highest and best" land use patterns.

Thus it is clear that realization of the "optimal" land use patterns (with "optimal" defined as being public cost-minimizing and benefit-maximizing land use patterns, with environmental costs and benefits included) requires governmental interference in the

private land market (5). Land use planning, and the zoning regulations that are supposed to be based on it, are the most well-known examples of this type of government interference.

The effectiveness of government land use management depends heavily on planning techniques that make systematic use of information on the physical, built, and natural environment; information that is not reflected in the market economy. The importance of considering the natural environment when developing land use plans has been emphasized for more than a century by many well-known professionals, including lawyer George P. Marsh, landscape architect and park designer Frederick Law Olmsted, Scottish biologist and planner Sir Patrick Geddes, and American forester Benton McKaye (6). However, a systematic approach was lacking until the development of land suitability analysis.

Suitability analysis examines the problems that may result from development in various land areas. It reflects the degree to which the natural and manmade qualities of the land are economically and environmentally suited for a particular use (7). The technique is based on the idea that hydrologic, geologic, biologic, existing land use patterns, availability of infrastructure, and other environmental features, when viewed collectively, will indicate the intrinsic suitability of a parcel of land for various uses (8). Land use planning and zoning based on such a system should produce development patterns that incur much lower environmental (indirect public) and direct public costs, while still conveying maximum public benefit.

A good land suitability analysis requires massive amounts of data on a wide range of physical characteristics for each parcel of land in the area to be planned. Furthermore, it requires the synthesis of this data into a manageable form. A map overlay technique is typically used for this data collection and analysis (9). Originally, the mapping and overlaying was done by hand using tracing paper and shades of gray to indicate suitability. But in many cases the analysis is so complex that it falls beyond the capabilities of this approach. Also, use of shades of gray and hand drawing can introduce significant inaccuracies into the data analysis. Fortunately, the development of high-powered personal computers and the explosion of GIS and related software has made it possible to employ computer analysis, using numerical weighting and coding systems, to more accurately accomplish this task (10).

Preparation of the Input Database

In both cases in which the ALLOT model was employed, a raster-based GIS database was first established using dBase III software (This database should be able to be utilized with vector systems such as ArcInfo, too). The study area was divided into square pixels of uniform size, and the information on each land characteristic relative to each pixel was stored in a database file with one record per pixel and one field per characteristic. The file was then converted to ASCII format for use as input into the model, which is written in SAS.

The following characteristics were selected for study based on the requirements for land suitability analysis, the attributes of the study area, and professional expertise regarding what factors are the greatest determinants of total public cost and benefit with respect to land development. Reports by the US Geological Survey, US Army Corps of Engineers, and the US Soil Conservation Service were very useful in collecting data on many of these land characteristics.

1. Slopes
2. Soils
3. Tree coverage
4. Road access
5. Visual features
6. Existing land use
7. Floodplains and wetlands
8. Proximity to water lines

Each land characteristic, in the course of analysis, was divided into different groups. This was done based on the wide range of variation within each characteristic and its particular influence on economic and environmental costs of different types of development. For example, there are many soil types in nature, and each one has different properties; these differences create wide variations in the suitability of soil types for various development types. For both the land use planning and landfill model applications, soil was divided into eight groups and pixels located in any of these groups were given a number to indicate the type of soil throughout the computation. The same sort of grouping and numbering was employed with all the other land characteristics. To illustrate, here are the categories used for the "existing land use" characteristic:

1. Vacant pixels near existing public or institutional uses

2. Vacant pixels near existing single family uses
3. Vacant, near multi-family existing uses
4. Vacant, near commercial uses
5. Vacant, near industrial
6. Vacant, near airport
7. Developed pixels
0. All other pixels

When the ALLOT model was used for landfill siting depth to bedrock was added to the above list, using the following categories:

1. More than 60 inches of depth to bedrock
2. Sixty inches or less depth to bedrock

Group numbers for each of the eight (nine for the landfill siting example, due to the addition of depth to bedrock) land characteristics were loaded into the database fields for each of the 4,506 records (one for each pixel) in the study area.

In addition, land use categories were evaluated to interact with the land characteristics. The land use categories for both examples are as follows:

1. Low density residential
2. Medium density residential
3. High density residential
4. Multi-family residential
5. Commercial
6. Industrial
7. Recreational
8. Public and institutional
9. Agricultural and vacant
10. Landfill (landfill siting example only)

The addition of depth to bedrock to the list of land characteristics and the addition of landfill as a future land use category illustrate the ALLOT model's flexibility; the user can easily tailor the list of input factors to individual needs.

Weighting

Each land characteristic was related to a land use category and given a weight based on suitability of the land characteristic attributed to the pixel for that particular land use category. For example, if pixel n were predominantly floodplain, the weight for residential land uses or landfill would be low, while the weight for open space land uses would be high.

Using logically consistent, mathematically valid methods of both assigning and combining weights is absolutely critical if the land suitability analysis process is to succeed (11). If great care is not taken in establishing a logically consistent weighting system that accurately reflects community goals and expert technical judgment, then the results of any land suitability model can quickly be rendered useless. Here is a summary of major pitfalls to avoid.

Assignment of weights is the point at which community goals and objectives are incorporated into the model. For example, if the community values wildlife highly, then those land characteristics that provide prime wildlife habitat will receive large weights as locations for parkland and small weights as locations for commercial development (assuming that the weighting system is based on the idea that the greater the weight, the better the location for that use). If the community feels that preservation of wildlife habitat is more important than provision of low-income housing, then the weighting system must be designed in such a way that a site that is equally well-suited for either use will be allocated to wildlife habitat, because that use is what the community has defined as "optimal" (subject to demand, of course, as discussed later in this paper).

Weight assignment is also the mechanism for including expert advice about the environmental and infrastructure costs and benefits of various land characteristics for various types of land use. For example, if a group of experts in the field have determined that a.) commercial development of floodplains carries heavy environmental costs, and b.) commercial development in areas without sewer systems will create a heavy economic cost to the taxpayers, then areas in floodplains and areas without sewer systems would receive low weights as sites for commercial development. Whether they received equally low weights would again depend on the judgment of the experts in the field. The Delphi method is a commonly used approach to arriving at a consensus on weighting using expert advice (Anjomani, 1987 and 1988).

Combining weights into an overall score is another area of difficulty. There has been much criticism of the methods used by McHarg and others (12), and this criticism was heeded in the development of this model. The model employs a simple additive approach, thus avoiding the exaggerated differences among areas that may result from multiplication and the problems of multiplying by zero or multiplying a positive by a negative number. The issue of how heavily to weight

community goals versus expert opinion must also be settled here.

Community leaders were used as sources for incorporating community goals into the weighting, while the students and faculty served as sources of expert technical judgment. The given weights varied from one to nine. When the land in the pixels was found the best for any specific land use category with regard to a given land characteristic, the value of 9 was assigned to those pixels. When the pixels were found to be neither good nor bad for any specific land use category and land characteristic, then the value of five was assigned to them. Values below five indicated the pixels' unsuitability for specific land use categories with respect to a given characteristic.

The weights for each group of land characteristics and each category of future land use are entered into the model as input data. The model begins by assigning one weight for each land use category to each of the land characteristic groups in the input database for each pixel. Thus, in the two examples, the future land use planning model had 72 numbers assigned to each pixel at this point in the model, and the landfill siting model had 90 numbers for each of the 4,506 pixels. The only limitation to using a PC for running the model is the size of the matrices created at this point; it may take hours to achieve results if one has many groupings of land characteristics, many future land use categories, many pixels, and/or a relatively slow computer such as an IBM 286. If a faster PC or a mainframe is used, however, or if time is not a problem, then there is no practical limit to the number of land characteristics, future land use categories, or pixels that can be handled by the model.

The model then adds all the weights associated with each land use category for each pixel; this step produced a total of nine weights per pixel for the land use planning example, and ten for the landfill siting example. Each of these weights represents the overall suitability of that pixel for a single future land use category. The value of these total weights can range from eight to 72 in the land use planning example, and from nine to 81 in the landfill siting one, since each overall weight results from adding the individual weights assigned to each of the land characteristics (each of which has a value of one--very unsuitable--to nine--very suitable).

The results of this assignment and adding process are stored in an output data file, which then becomes input for the second step of the model.

STEP TWO: ALLOCATING FUTURE LAND USE

Each land use category was evaluated separately in this part of the model. This was accomplished by first sorting the dataset on an individual land use category, forcing those pixels with the highest suitability scores for that future land use category to the top of the dataset column.

Next, the optimization model compares across columns (each column represents suitability weights for one future land use category) pixel by pixel, testing for the highest land suitability weight in each pixel. If the land use category being processed in this particular step was equivalent to the highest value in the pixel and demand for that land use category had not been satisfied, then the pixel was selected for that future land use; otherwise, the pixel was left for further processing.

When demand for any land use category is satisfied, the computer sets the weight for that land use category for all remaining pixels to zero prior to processing them for other land use categories. By doing this, unwanted but highly rated pixels for the original land use category were freed for selection for another category.

The process was repeated for each of the land use categories until demand for all categories had been satisfied. This required the computer to sort through all the pixels as many times as the number of land use categories; each sorting is referred to as a "round" in this paper.

Demand forecasts are developed, using whatever standard methods appeal to the user, prior to running the model. In the examples, forecasts of population were developed for the study area using several different population- and employment-based techniques. The result was a range of forecasts, from which three were selected for use in the model: maximum growth, minimum growth, and most likely growth scenarios. These three were then converted to acres of land needed for each of the future land use categories, again using a variety of standard planning and forecasting conversion techniques. Finally, the acreage was converted to numbers of pixels, thus ending with a high, low, and most likely number of pixels needed for each of the future land use categories. The model was then run three times, once for each of the three growth

scenarios, and the result was three alternative land use allocation patterns.

The output of ALLOT is a dataset allocating each pixel to a future land use category. These results were fed into a SASGRAPH program to produce maps of future land use patterns; however, the dataset could be used as input into a wide variety of mainframe and PC-based mapping software, as this part of the program is separate from ALLOT and so is not considered as a part of it.

ANALYSIS OF RESULTS

The intention of the model application for siting was to select the areas most suitable for landfills. If future demand for all of the land use categories had not been involved in the analysis, the computing procedure would have been significantly simpler: all the model would have needed to do would have been to allocate suitable pixels for landfill purposes without paying attention to the rest of the land use categories and the number of pixels being allocated. Unfortunately, the output from this approach would have been incorrect: the result would have been a map showing only the areas that are good for landfills, and this is not what one would consider the best use of the land or optimized land use planning. Optimization can be achieved only when all of the land use categories are involved in the calculation and the demand for each one has been determined. A map illustrating only those areas that are most suitable for landfills means little for two reasons. First, the same areas might be even better suited for apartments or industry. Second, consider a case in which there will be very low future demand for landfill sites, but nearly all of the area is ideally suited for landfills. In this case, reserving most of the area for landfills cannot be considered as optimal land use allocation, because the act of reserving so much land for an unneeded purpose will push those uses for which there is significant demand into very undesirable areas (assuming that there is enough acreage available for them at all). Since it specifically addresses this issue, the ALLOT model is different from any other model with which the authors are familiar.

On the other hand, involving future demand increases the complexity of the modeling and computation procedure. For this reason, a great deal of time was spent on programming the model so that its counter would respond correctly to the needed number of

pixels for each land use category and select the exact number.

Keeping track of the number of allocated pixels to any land use category, and comparing it with the demand throughout the different rounds of the model, is the most difficult part of the construction of the ALLOT model. Nevertheless, as a result of intensive programming, the model successfully selected the suitable pixels for each land use category based on future demand.

Future applications of this model are virtually unlimited. Its ability to run on a standard IBM-compatible PC makes it much cheaper to use than most GIS systems, which can require purchase of thousands of dollars worth of computer hardware (13). Additionally, the model's ability to quickly and efficiently allocate future land uses makes what used to be a task requiring many months of hand labor a matter of hours. This frees planners from the tyranny of attempting to forecast growth patterns exactly; rather, a wide variety of alternative forecasts can quickly be mapped in environmentally compatible patterns. These can then be compared with expected growth patterns without government guidance (what WOULD occur rather than what SHOULD) to vividly illustrate the total public cost of undirected growth. Incidentally, the model can also map this scenario if land characteristics are removed that typically do not count in a developer's calculations (wildlife habitat, for example) and weights are changed to reflect the private developer's thinking rather than community goals. Finally, the model can be an invaluable site selection tool, particularly for LULUs (locally unwanted land uses) such as landfills (14). It provides a defensible rationale for site selection and land use planning, producing results that are surely an improvement over present techniques.

References

- (1) Bright, Elise M. "Richland-Chambers Lake Area: A Vision of the Future," CIRP 5330 Project Planning Class Project. Arlington, TX: Institute of Urban Studies, The University of Texas at Arlington, 1989.
- (2) Nazem, Parviz. "Municipal Waste Management Plan and Application of GIS in Landfill Site Selection," unpublished final project. Arlington, TX: School of Urban and Public Affairs, The University of Texas at Arlington, 1990.
- (3) Nehman, Gerald; Griffin, Joan M.; and Duke, Kenneth M. "Land Use and Environmental Planning," in Let's Plan Our Use of the Land, v. 7, no. 1 (1975). Columbus, OH: Research Outlook, Battelle National Laboratories.
- (4) Ortolano, Leonard. Environmental Planning and Decisionmaking. New York: John Wiley and Sons, Inc., 1984.
- (5) McHarg, Ian. Design with Nature. Garden City, NY: Doubleday Natural History Press, 1969.
- (6) Mumford, Lewis. The City in History. New York: Harcourt, Brace & World, Inc., 1961.
- (7) Schneider, Devon M., and Amanullah, Syed. Computer-Assisted Land Resources Planning. Planning Advisory Service report number 339. Chicago: American Planning Association, 1984.
- (8) Mutunayagam, N. Brito, and Bahrami, Ali. Cartography and Site Analysis with Microcomputers. Chicago: American Planning Association, 1986.
- (9) Anjomani, Ardeshir. "The Overlaying Map Technique: Problems and Suggested Solutions," in Journal of Planning Education and Research, v. 4, no. 2 (1984).
- (10) U. S. Environmental Protection Agency. Geographic Information Systems Handbook. Washington, D.C.: U.S. Government Printing Office, 1989.
- (11) Anderson, Larz T. Seven Methods for Calculating Land Capability/Suitability. Planning Advisory Service report number 402. Chicago: American Planning Association, 1987.
- (12) Hopkins, Lewis D. "Methods for Generating Land Suitability Maps: A Comparative Evaluation," in Journal of the American Institute of Planners, 1977.

(13) Gordon, Steven I. Computer Models in Environmental Planning. Chicago: Planners Press, 1985.

(14) Melachrinoudis, Emanuel, and Cullinane, Thomas P. "Locating an Undesirable Facility Within a Geographical Region Using the Maximum Criterion," in Journal of Regional Science, v. 25, p. 115 (3), (1985).