LAND USE ALLOCATION OPTIMIZATION MODELS APPLIED TO FUTURE USE AT THE U.S. DOE'S MAJOR NUCLEAR WEAPONS SITES

Report 31

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Abstract

A simple land use allocation model is described as a way of organizing and analyzing future use options at major DOE weapons sites. The advantages and disadvantages of this model and alternatives are described.

1. Introduction

People see and value the same things in very different ways. Regarding land use near large industrial hazards, some value flora and fauna more than anything else, and consequently, they value the land between them and the hazard as a place to sustain local ecological systems more than they value it for any other land use. Others value protecting human health the most, and so they favor using the land to buffer people from nearby potential hazards, even if that means severely disturbing it. For some people, gaining profit from land takes precedence. In short, our collective expression of our values and priorities as manifest on the landscape is anything but simple.

Savannah River, Hanford, Rocky Flats, Oak Ridge, INEEL, and some other DOE sites had a national mission to develop, test and produce nuclear weapons. That mission directed land use for about a half century. With the end of the Cold War, the DOE's priorities became more complicated, as have their land use choices. The weapons mission exists at a few sites, but co-exists with environmental management. At other sites, there is no weapons mission, and environmental management is the mission. At sites such as Savannah River, ecological research, logging, and recreation have been practiced for years, and in a way have been additional but lesser priorities than defense and environmental management.

In the new millennium, we can expect the traditional missions of defense and environmental management to be challenged and/or replaced by other missions. Long range land use planning and stewardship were not issues at these sites during the Cold War. But now they are, and the Department is trying to figure out ways of taking a host of potentially competing national, regional and local needs, as well as its own, and weaving these into a land use design and management plan. At one site, long range land use and planning and stewardship may mean a high degree of security and open space with no public access. At a second site, hunting, fishing, bird-watching, hiking, and ecological research may co-exist with industrial and on-site environmental management. The land use choices are set by the DOE's objectives; legal agreements between the department, EPA, and the states; community preferences; and business interests.

Simultaneous quantitative comparison of the implications of land use options is the most objective way of trying to understand the advantages and disadvantages of different options and of the relationships among them. While the information needed to make precise comparisons is never completely available, the exercise of settling on an approach and putting together the best available data prompts scientists and managers trained in different disciplines to talk and work with each other around a common focused goal. The results produced from these efforts can be sufficiently insightful to guide decision-makers in their deliberations. The purpose of this report is to discuss land use optimization allocation models, describe one it detail that I believe can help CRESP and others focus on information requirements, and help DOE and stakeholders in translating their values and preferences into future use choices.

2. Land Use Allocation Models

For almost two centuries, we have known that economic theory can be used to allocate land use in concert with health, environmental and ecological theories and data. However, the ideas of Von Thunen (in Hall 1966), Hurd (1903), Haig (1927), Alonso (1964) and others were described with only the simplest equations and graphical illustrations until the computer was developed. Computers have made it possible to test the reality of these models (see Greenberg 1978 for a review).

A typical land use optimization allocation model has an objective that is constrained by supply and demand. For example, many models built during the 1960s attempted to find the best location for different types of housing. The objective was to maximize the value of an area as seen through the eyes of potential consumers. More specifically, these optimization models maximized the net difference between the value to potential residents in terms of convenience, type of neighborhood and other attractions and the cost including property and transportation. This type of model typically had two important constraints. One was the supply of land for building each type of housing in each market area. The second was the demand for housing estimated through market studies.

Another typical model minimized transportation costs subject to a series of supply and demand constraints. For example, it is important to have emergency medical centers near people. The objective was to locate sites to minimize the time it took emergency units to reach neighborhoods. The constraints were the forecasted demand for emergency services and the supply of equipment, people, and available land.

By the mid-1970s analysts were able to use enhanced computing power to employ non-linear modeling methods. These methods yield slightly more precise solutions than possible with linear models. In addition, more computing power means multiple solutions can be obtained, which is important because the optimum solution may not be legally or socially acceptable.

Despite the increase in computing power, applications to real world problems are relatively few for five reasons. First, a huge amount of data is required, which normally is not available and stops analysts before they start. Second, some researchers are so faithful to their theories that unrealistic assumptions are inserted into models, producing unrealistic results. Third, many of the variables examined in the models interact (accessibility and price), a reality difficult to eliminate without making the models extremely difficult to calibrate and then explain. Fourth, given the first three reasons, researchers sometimes put together watered-down models that are useless to decision-makers. Fifth, allocation models, especially the most complicated ones, have not necessarily produced more accurate results than simpler ones. There are exceptions, for example, Hokkanen, Lahdelma, and Salminen's (1999) application to choosing among different development patterns for the Helsinki cargo harbor.

Models that have been successfully applied have tended to focused on a specific policy issue, where the decision-making responsibility is clear, and the tradeoff between policy needs and scientific elegance has been made in favor of policy needs.

3. A Land Use Allocation Model for DOE Sites

The objective function maximizes the difference between the value of the land and cost of making it suitable for development:

$$\textbf{(1)}\quad \textbf{\textit{Maximize:}}\qquad Z = \bullet_{ijkt}\ (E_{ijkt} - C_{ijkt})\, X_{\mathbf{ijkt}}\,,$$

where $\boldsymbol{E}$ is the per acre economic value of land; $\boldsymbol{C}$ is the per acre cost of making it suitable; and $X_{\mathbf{ijkt}}$ is the number of acres of land devoted to land use activity $\boldsymbol{i}$ in geographical region **j** in land use suitability zone **k** during time period **t.** The objective function will seek to select the most economically beneficial choices, which we can constrain with health, social, ecological, aesthetic and other constraints.

Assume that the area we are studying is 10 square miles made up of 10 regions, that is, the regions, or **j**, are 1-10. Regions, of course, can be much larger or smaller. For example, I have worked with regions as large as northern and central New Jersey and an area as small as a single waste management site. Likewise, in this case we can assume each of the ten areas is one square mile. But there could be 20 areas, each of ½ square mile. The area choices depend solely upon the needs of the users and the quantity and quality of data.

For purposes of this illustration, we will select five potential land uses types, or ***i:***

1. Open space with no human entry, except as required by the DOE for maintenance or other DOE-related defense and environmental management activity;
2. Open space with light recreation, such as allowing hunting, fishing, hiking;
3. Open space with more intense recreation, such as laboratory work, campgrounds, taking people on tours;
4. Light business, such as commercial laboratories, industrial incubators for environmental management, warehousing,
5. More intense business, such as production facilities, large commercial and warehousing activities.

Note that these are five of many possibilities. We have as many choices as are realistically desirable and feasible.

The regions are separated into four suitability zones types, or **k.**

1. Undeveloped (no or limited roads and other infrastructure) and no obvious damage (no (nuclear, chemical, natural hazard, or other damage).

2. Undeveloped and some damage (some evidence of nuclear, chemical, natural or other damage or hazard)

3. Partly developed (some roads and/or infrastructure) and no obvious damage

4. Partly developed and some damage.

Again, please note that these are illustrations of suitability types. We certainly can develop more designations than these. The point is to describe them in a way that people will understand and can work with.

Lastly, five time periods, or **t,** are defined with five-year time intervals. At each 5-year snapshot, only undeveloped land may be allocated. This means that land the DOE already uses for defense and environmental missions, or requires for a security zone will not be allocated. If the DOE chooses to reallocate land during a time period, we can handle those changes within the model by changing the availability constraints. Land that the DOE may need in the future, but not within the next 5 years, can be temporarily allocated to the first land use or first two land use activities defined above, which can be considered to be temporary allocations.

The maximization process is constrained by a series of linear constraints. A series of these relate to land availability.

$$\textbf{(2)} \quad \bullet_{i} \; X_{\mathbf{ijkt}} \leq \mathbf{b}_{jkt} \, ,$$

where $\mathbf{b}_{jkt}$ is the total land available for use in region **j** in land use suitability zone **k** during time period **t.** This means that allocations to all land uses cannot exceed available land.

$$\textbf{(3)} \quad \bullet_{k} \; X_{\mathbf{ijkt}} \leq \mathbf{b}_{\mathbf{ijkt}} \, ,$$

where $\mathbf{b}_{\mathbf{ijkt}}$ are constraints for each land use activity in each region, land use compatibility zone and time period. This constraint means that we won't allocate more than a certain amount of each land use activity to a particular suitability zone.

Next, we write land use recreation-education constraints that express the relationship between land use, people and exposure.

$$(4)\ \ a_2 \bullet_{jk} X_{2jkt} + a_3 \bullet_{jk} X_{3jkt} \leq r_t,$$

where the a_2 is a coefficient expressing the number of people per light recreation activity, and a_3 is the coefficient for more intense recreation; r_t is the total non-DOE recreation-education population allowed on site by the DOE to make sure chronic exposure, acute exposure, ecological limits, and other concerns are addressed. These coefficients are a way we can control the number of recreation people allowed on the site. They can be written as people-hours for purposes of risk analysis. And, of course, we can write one set for human exposure and another set for ecological. The above is an indication of the form they take.

$$(5)\ a_4 \bullet_{jk} X_{4jkt} + a_5 \bullet_{jk} X_{5jkt} \leq w_t,$$

where the a_4 and a_5 coefficients express the number of workers per commercial activity, and w_t is the total workers permitted. As before these can be written as exposure-hours instead of people.

The next set of equations would be based on demand for these activities as follows:

$$(6) \bullet_{jk} X_{2jkt} \leq b_{2t}$$

$$(7) \bullet_{jk} X_{3jkt} \leq b_{3t}$$

$$(8)\ \bullet_{jk}\ X_{4jkt} \leq b_{4t}$$

$$(9)\ \bullet_{jk}\ X_{5jkt} \leq b_{5t}$$

These are based on demand studies and set the limits based on the need rather than or in addition to human and ecological health limitations.

We know from our survey work that many people want open space and security and health buffers at these sites. We can write this as a constraint as follows:

$$(10)\ \bullet_{i=2\rightarrow 5}\ X_{ijkt} \leq .333 \bullet_{i=1}\ X_{ijkt}$$

Equation 10 says that for every acre of land use assigned by activities 2-5, three acres must be set aside for activity 1, which was open space and limited access. This kind of constraint can be written for any number of land use activities relative to one another.

The last equation type says that the algorithm must not allocate negative amounts of land use of one type in order to maximize financial benefit.

$$(11)\ X_{ijkt} \geq 0$$

4. Discussion

The model described here is simple and functional. Nevertheless, you can see the kind and amount of information needed to use it. We will need to choose a set of feasible land uses (opportunity for stakeholder input), tie their use to human and ecological risk, estimate the demands for the land use activity(stakeholder input), the economic benefits of allowing each land use, and the costs to the DOE and others of preparing the land for use.

More complex, non-linear and dynamic models are possible. They would allow us to follow the set of activities and places continuously through time. As noted earlier, few of the more sophisticated models have been used because of data demands and communication problems. If we want to pursue this, I suggest a meeting of key CRESP and other researchers to go over it.

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