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LAPA - A Graphical Analysis Technique for Prioritizing Geothermal Leasing Activities on Public Lands*

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ABSTRACT

This paper describes the development of a composite indicator for prioritizing geothermal leasing activities on public lands. LAPA utilizes fuzzy set software developed by the GRAD/SEEDIS projects at the Lawrence Berkeley Laboratory. It is an automated procedure which allows the analyst to use subjective categories to prioritize geothermal areas according to their unleased energy potential, the level of private response, and the potential for pre-lease environmental delays.

THE NEED FOR DECISION-SUPPORT SYSTEMS

Computerized information systems are now routinely used to monitor and evaluate geothermal development in both government agencies and in industry. Effective use of these systems to support decision-making requires the development of software tools that can accommodate the analyst's need to manipulate large amounts of data, incorporate appropriate subjective criteria, and communicate results in an effective manner. The advantage of interactive software is that it allows a decision-maker to iteratively examine the latent information content of large data sets. Such tools can be easy to use; they benefit the analyst by allowing him to probe data without disrupting the "think continuous" process inherent in analysis.[1]

This paper describes an experimental interactive graphics procedure for prioritizing geothermal leasing on public lands. The authors would like to express their appreciation to the staff of the Minerals Management Service (formerly Conservation Division, U.S. Geological Survey), members of the Bureau of Land Management, and the U.S. Forest Service for their assistance. The results presented in this paper should be regarded as preliminary and illustrative. They are the sole responsibility of the authors and do not in anyway reflect the positions or opinions of these agencies.

USING SUBJECTIVE CATEGORIES TO SUMMARIZE DATA

One aspect of data analysis is the need to get quick answers to simple questions. Data can be characterized quickly and easily using subjective categories expressed in everyday language. Some examples are: "high" unemployment rate, "high" energy potential, "positive" response, "minimal" delay.

Fuzzy set theory and operations provide a model for transforming numerical data into subjective categories.[2,3] In traditional set theory, objects may either belong or not belong to the set in question. The essential idea in fuzzy set theory is that each element in a universe of discourse is associated with a degree of membership: a number between 0 and 1. The "more" an element belongs to a set, the higher the degree of membership.

Figure 1 shows how a data set fits into a characterization of "high" unemployment. Unemployment rates below 6% do not fit that characterization at all; rates from 6 to 10 fit increasingly better; rates above 10 fit best.

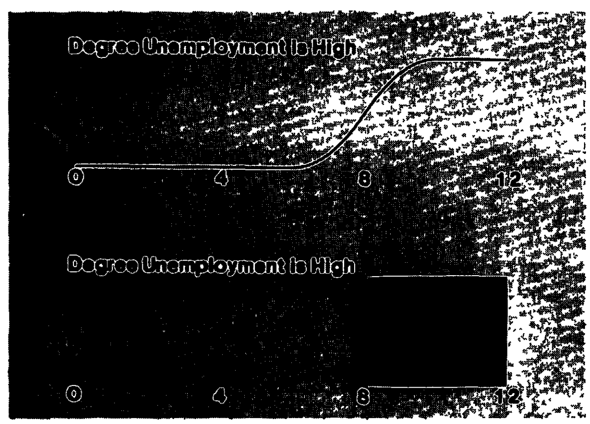

Figure 1. "High" Unemployment

The bottom of the figure shows how degrees of membership can be conveyed by a continuous black and white scale. Notice that one can only differentiate among rates in the area between 6 and 10. There are clear-cut cases of full membership above 10, and clear-cut cases of non-membership below 6. Thus, fuzzy set graphical analysis can be used as a technique that allows the analyst to focus his attention on areas where it is needed, and to ignore unnecessary detail.

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FUZZY SET OPERATIONS

Fuzzy sets can be combined in several ways that are equivalent to the linguistic expressions "or", "and", and "not".[4]

The union of two fuzzy sets A and B is denoted by A U B and can be interpreted as the maximum of "A or B or both".

The intersection of two fuzzy sets A and B is denoted by A B, whose membership function is the minimum of each corresponding membership value.

The negation of a fuzzy set A is a fuzzy set whose membership function is the complement to 1 of A's membership function.

PRIORITIZATION OF GEOTHERMAL AREAS ON FEDERAL LANDS

The prevailing federal policy is to increase leasing of federal lands for geothermal exploration and development consistent with the preservation of environmental values.[4] In order to maximize the benefit (early contribution to power-on-line) of lease sales, it is useful to prioritize leasing of identified resource areas according to their potential for successful development. In the development of the Leasing Action Priority Area (LAPA) indicator, we have focused on the idea of the marginal lease, i.e., where should the surface management agency make available additional acres of federal lands?

Preliminary assessments of geothermal resources on federal lands have been carried out by the U.S. Geological Survey and in cooperation with state agencies.[5] Using information available from federal agencies,[6,7,8] a composite indicator consisting of three factors and incorporating six quantitative measures was developed to reflect leasing decision criteria.

An ideal geothermal area would have:

- o High unleased energy potential;
- o Historically positive response from private developers;
- o Minimal environmental delay due to incomplete environmental impact studies.

Evaluating geothermal areas against these criteria is not a well defined task. The numerical precision of indicators may be of limited value because available data may be imprecisely measured, or inherently imprecise, as in the use of estimates, projections, or proxy variables. In addition, there may be differences of opinion as to relative importance of the criteria and differences as to how faithfully the indicators represent the criteria. Un-representatable criteria, such as political considerations, (e.g. "This area has high unemployment and needs the influx of jobs which could be created by leasing this geothermal tract") need to be folded in by the decision maker.[4]

METHODOLOGY

The composite LAPA indicator is obtained using the GRAD/SEEDIS programs in five steps:

1. Select and compute numerical indicators to represent the criteria.
2. Describe the ideal case for each indicator.
3. Modify membership values by importance weights.
4. Combine indicators using fuzzy set operations, and display degree of fit to the ideal case using a continuous color scale.

These steps are performed with the assistance of an 'expert'; someone who is knowledgeable about the data, the criteria, relative importance, etc. An analyst might interactively modify the indicators or the descriptions of ideal cases.

1. Select and Construct Indicators

o How much unleased energy exists in the geothermal area?

The unleased factor (UF) is defined as

$$UF_i = \frac{\text{acreage not yet offered}_i \cdot \text{energy potential}_i}{\text{Total acreage offered for lease}_i}$$

Notice that this indicator (UF) only roughly represents the concept "unleased energy potential still available for private development". The imprecision in this quantity comes, for example, from the fact that the geothermal resource may not be evenly distributed, and the energy potential is only an estimate.

o What is the level of private interest in leasing the area?

The private response (PR) is obtained from four indicators: the number of bids per lease sale in the most recent year (BL); the number of noncompetitive applications (NC), if any, in the area; the average bonus per acre offered paid in the most recent year (BB); the ratio of acres relinquished or terminated (after a lease) to the total acreage leased (AR).

BL is a measure of how interesting the land offered for lease has been to the private sector recently. NC is used to capture the same dimension for lands which have not been offered for lease on a competitive basis. We constructed a private interest indicator (PI) by combining these two indicators. In other words, if either BL or NC or both are high, we consider that private interest for the area has been manifested.

BB is a measure of the marginal value of land in the area to the private investor -- lease sales in the most recent year are selected as the best approximation.

AR is a measure of how successful post-lease private activity has been in the area. For the purpose of constructing this indicator, we have assumed that relinquishment/termination follow unsuccessful drilling and exploration, but it should be considered that other reasons for relinquishment/termination may be that the tract was leased on a speculative basis or that the investor's acreage limitation has been reached.

PR is computed as the intersection (minimum) of PI(BL and NC), BB, and AR.

o What is the potential for pre-lease delay from environmental factors?

The environmental delay factor (EF) is measured by the amount of unassessed, unoffered acreage over unoffered acreage in the geothermal area

$$UU = \frac{\text{unassessed, unoffered acreage}}{\text{Unoffered acreage}}$$

UU is a measure of the potential delay incurred in the pre-lease process rather than a measure of the potential costs and benefits of environmental regulations.

Following the procedures for fuzzy set operations, a composite LAPA indicator is obtained as the intersection of the three main decision criteria as follows:

$$LAPA_i = \mathrm{Min}[UF_i,\ \mathrm{Max}(BL_i, NC_i),\ AR_i, BB_i, UU_i]$$

Sample data for individual indicators in 10 KGRAs are shown in Table 1.

Table 1. Sample Data for LAPA

UF Unleased Factor
BB Bonus Bids per acre
BLNC either Bids per Lease
Non-Competitive leases
AR Acreage Relinquished
UU Unleased, Unassessed

KGRA	UF	BB	BL	NC	AR	UU
CA Lake City	460	215	6	42	.75	0
CA Mono-Long V.	2018	116	10	6	.00	0
CA Salton Sea	2400			10		1
ID Castle Creek	59	8	23		.31	0
ID Crane Creek	195	17	1	19	.00	0
ID Raft River	26	2	1		.00	0
NV Gerlach	3	9	1		.23	0
NV Stillwater	352	18	2	0	.25	0
OR Alvord	45	64	13	23	.39	0
OR Newberry	700			151		0

2. Describe the Ideal Case for Each Indicator.

The numerical indicators constructed act as proxy variables for leasing criteria. At this point, analysis can be shifted from the numerical values themselves to broad categories appropriate for each indicator, such as "high" or "low". The primary motivation for a shift in focus is the opportunity for reducing the cognitive load on the analyst, that is, the amount of information needed to be recalled in "sizing up the situation" for the decision at hand.

For example, the analyst is searching for areas with high values for UF, and low values for UU. Attention can be directed to those areas in the sample where UF is high to some degree, and UU is low to some degree.

"High" in UF is defined relative to a range and a reference point, the median.

This definition of "high" was chosen to approximate users' intuitions--interviews with experts indicated that the threshold value of interest was about 300 MWe for electric power production. Further, the median is a robust measure of location. Exactly half the cases will fit the ideal case for each indicator, at least to some degree. In fact, experts preferred not to differentiate cases above the median for this indicator. Because of this, the more inclusive fuzzy set "not low" was used, so that all cases above the median fit perfectly, and all except the very lowest have some (non-zero) degree of fit.

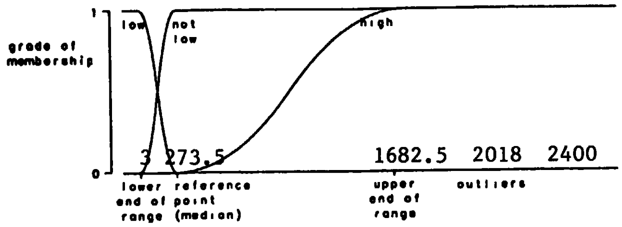

Figure 2. Membership Function Curves for UF

3. Importance Weights.

Importance weights are applied to each indicator by raising membership values to a constant power (the importance weight for that indicator). The less important the indicator, the closer to zero is the weight, and the nearer to one is the modified membership value.[9] Raising membership values according to importance helps overcome the effect of poor scores on less important indicators. We deferred the assignment of weights to experts involved in the leasing process but combine their judgements in a systematic way according to fuzzy set rules.

Combine the Indicators.

The indicators can be combined in two ways: using fuzzy logical operators, or integrating the degree of fit information visually.

Table 2 shows the membership values for unadjusted indicators.

Table 2.

Not Adjusted for Importance

CI	KGRA	UF	BB	BLNC	AR	UU
.00	CA Lake City	1.00	1.00	1.00	.00	1.00
1.00	CA Mono-Long V.	1.00	1.00	1.00	1.00	1.00
.00	CA Salton Sea	1.00		.51		.00
.07	ID Castle Creek	.07	.15	1.00	.96	1.00
.79	ID Crane Creek	.79	.99	1.00	1.00	1.00
.00	ID Raft River	.01	.00	.00	1 00	1.00
.00	NV Gerlach	.00	.33	00	1.00	1.00
.11	NV Stillwater	1.00	.99	.11	1.00	1.00
.03	OR Alvord	.03	1.00	1.0Q	.84	1.00
1.00	OR Newberry	1.00		1.00		1.00

In this example, default rules for logical operators were used to produce the combined indicators for 10 KGRAs. These default rules model the case where there is no interaction among the indicators. That is, they are equally important and no consideration is given to tradeoffs, exceptions, or missing values.

Figure 3 is a display of the combined indicators using a continuous grey scale.[11] It is easy to see from the leftmost column that Mono, Crane Creek, and Newberry satisfy all the criteria. Three others, Castle Creek, Stillwater, and Alvord fit the ideal case, but not as well.

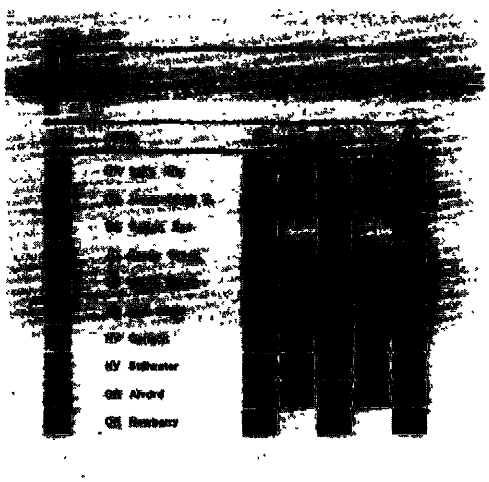

Figure 4. Composite LAPA Indicator

Degree of fit to the ideal case for each indicator is shown at the right. The value of this display is that the analyst may prefer to consider importance, tradeoffs, exceptions, and missing values in the context of a particular data set.

For example, comparing the first two rows (Lake City and Mono) brings up the question: can you make an exception of AR? Comparing each one vs. the last row (Newberry) calls for a judgment about missing values with BB and AR. How should missing values be interpreted? It is legitimate and often easier to evaluate choices when faced with real data, rather than hypothetical situations. The trade-off in using a descriptive approach for exploratory data analysis is that one can avoid the up-front investment involved in a prescriptive method, such as setting up a model of rational behavior involving many judgments about exceptions and tradeoffs in importance for every conceivable situation.

CONCLUSION

To summarize, LAPA can be used as a decision-support tool that allows the analyst to incorporate judgement in the evaluation of data relevant to lease actions. It provides an automated procedure for summarizing information in a manner that reduces the load on the analyst's short-term memory. Data is presented according to how well it matches a given set of leasing decision criteria, and irrelevant numerical precision is dispensed with. Both the clear-cut match and cases having different degrees of fit are easily summed up by color graphics that support almost spontaneous visual tradeoffs between objectives. The ideal of cognitive economy in information systems is served by giving the decision-maker access to better summary information with less effort.

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ALPHABETICAL INDEX OF AUTHORS

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C

G

H

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R

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T

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W

Y

Z