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LAPA: A COMPOSITE INDICATOR FOR PRIORITIZATION OF GEOTHERMAL-LEASING ACTIVITIES ON FEDERAL LANDS IN THE UNITED STATES

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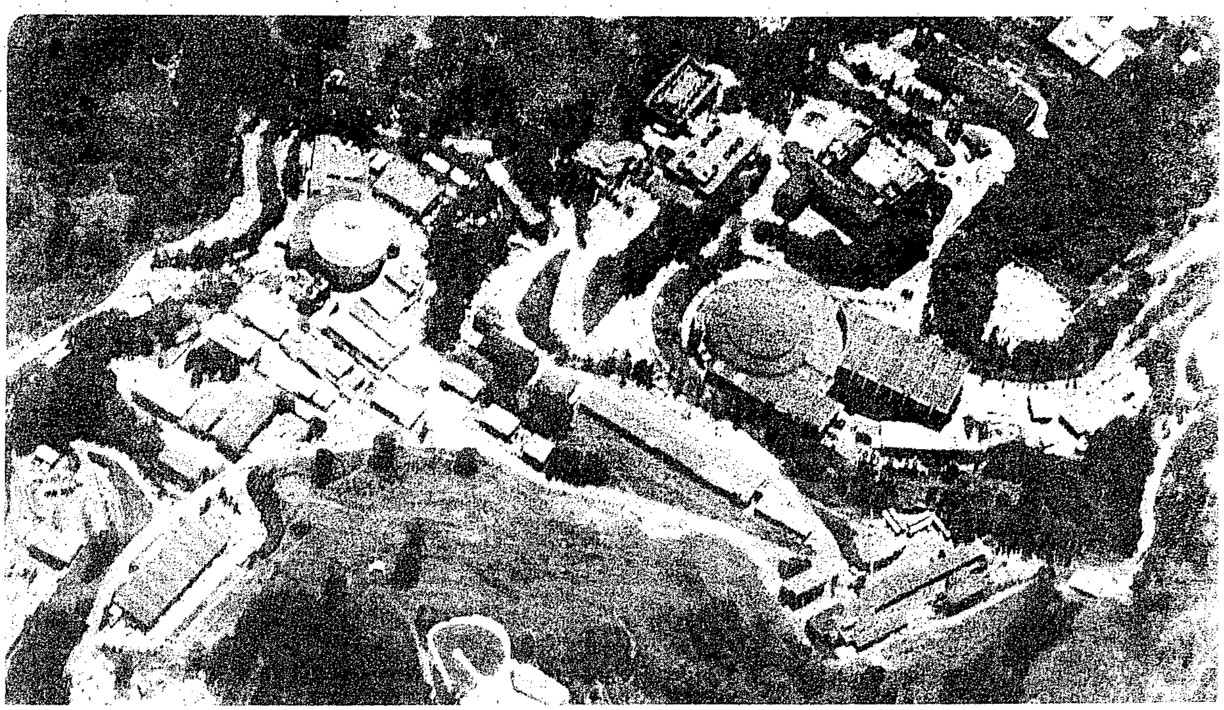

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DISCLAIMER

LAPA: A Composite Indicator for Prioritization of Geothermal Leasing Activities on Federal Lands in the United States

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SYNOPSIS*

An important federal policy in support of geothermal development in the United States is the streamlining of the leasing process on federal lands to facilitate early leasing of the most promising geothermal areas for private sector exploration and development. The National Geothermal Information Resource Project is participating in this effort through the development of a composite Leasing Action Priority Area (LAPA) indicator, using information collected in the Geothermal Resource Areas Database (GRAD) and records maintained by the United States Geological Survey and the Bureau of Land Management. Three factors, incorporating seven quantitative indicators, have been selected to represent criteria for prioritization of geothermal areas. These indicators reflect important dimensions for monitoring and estimating the contributions of particular areas to energy production goals on federal lands. Using computerized graphics and data analysis software developed by the Social Economic Environmental Demographic Information System (SEEDIS) project at LBL, weighting of these indicators by experts is integrated to produce a composite indicator for evaluation of leasing activities.

This paper will describe the selection of specific indicators for areas which have a high unleased energy potential, where the response of the private sector is positive, and where the potential delay from environmental factors is minimal. It will also discuss the development of the composite LAPA indicator and the application of fuzzy set operations for incorporation of expert judgments about the leasing process.

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1. Introduction.

Leasing of federal lands to conduct exploration activities is a first step which makes available identified resources for potential development. The responsibility of DOE's Leasing Policy Development Office (LPDO) is to set energy production goals on federally owned lands with geothermal potential and to assure that the leasing schedule implemented by the Bureau of Land Management and the U.S. Forest Service is effective in meeting these goals.

Prioritization of Known Geothermal Resource Areas (KGRAs) for competitive leasing is important because both the public agency's and the private sector's resources are limited, and an unlimited offering of all available land can overtax available resources. In general, target leasing areas are those areas with a high unleased energy potential, where the response of private developers has been positive (which shows that the site offers good economic opportunities) and where the potential delay as a result of incomplete environmental assessments are minimal. The National Geothermal Information Resource Project is supporting this effort through the development of a composite Leasing Action Priority Area (LAPA) indicator, and use of information collected in the Geothermal Resource Areas Database (GRAD) and records maintained by the U.S. Geological Survey and the Bureau of Land Management.

The key issue for the design of a leasing decision support system is how each area's potential for successful development can be evaluated on the basis of available information. It is important to keep in mind at the outset that leasing decisions require inputs from many sectors for full understanding and resolution and that there are no unique set of decision criteria applicable to all situations. The potential for enhanced decision quality can only be realized by the thoughtful organization and presentation of data that is sensitive to both the capabilities and the constraints placed upon the decision-maker in the implementation of public policy and the scheduling of lease sales.

In this regard, numerical analysis alone, comparing statistics on resource potential, acreage under lease, bonus bids paid, etc. at different areas may be of limited value to the decision-maker because he or she often needs to exercise subjective judgment in leasing decisions and does not care about precise figures, but thinks of the potential for one area as "higher" or "lower" relative to some ideal prototype. The use of categories for hypothesis testing and exploratory data analysis are also helpful where there is an inherent imprecision in estimates for specific indicators such that focusing on precise values can be misleading.*

In this context, fuzzy set theory[1] and fuzzy decision analysis[2,3]

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* For example, significant energy potential among identified geothermal areas cannot be described exactly because of the large uncertainties at the present stage of geothermal development in the estimates of recoverable energy even though a precise number is assigned.

have emerged in the last 10 years as procedures that provide a systematic way of diacritically structuring complex decision problems using linguistic variables where numerical precision would be irrelevant or inappropriate. The use of linguistic expressions approximate natural language and is often closer to the thinking process of the decision-maker.

This paper will describe the selection of numerical indicators, the transformation of numerical indicators into linguistic variables, the incorporation of multi-expert weighting of decision criteria, and the application of fuzzy set rules to the development of the composite Leasing Action Priority Area (LAPA) indicator.

The Appendix provides a brief introduction of fuzzy set theory with examples, notation, and elementary operations (union, intersection, and negation). The importance operator, fuzzy decision rules, and the representation of linguistic variables through fuzzy sets are discussed.

2. Selection of Indicators.

The three factors selected to reflect leasing decision criteria for prioritization of geothermal areas are: unleased energy potential; private response; and environmental delay. (See Figure 1).

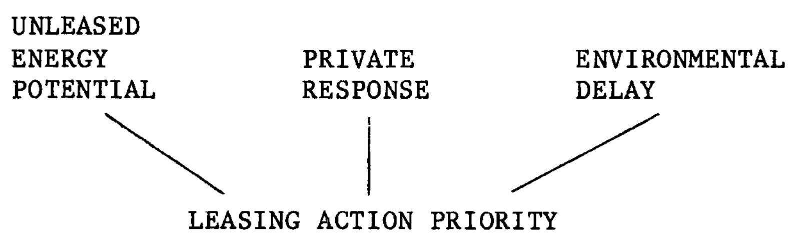

Figure 1.

The choice of these criteria is based on a review of DOE program documents describing the goals of the federal leasing geothermal program.[4,5] Numerical indicators are then selected from records maintained by the Geothermal Resource Areas Database (GRAD), the U.S. Geological Survey, and the Bureau of Land Management (BLM).[6,7,8,9]

In the development of LAPA and in the choice of indicators, 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?

The amount of local energy potential still available for private development is represented by the unleased factor (UF) for the geothermal area. UF is defined as

$$UF_i = \frac{\text{Fed acreage not yet offered for lease in } i \times \text{energy potential in } i}{\text{total acreage offered for lease in } i}$$

This indicator implicitly assumes that the energy potential per acre in the unoffered portion of the area is approximately the same as it is in the fraction already offered for lease. UF as defined is a conservative estimate of the resource potential in a given area because the acreage not yet offered for lease rather than the unleased acreage is used as the numerator of the indicator.* It is assumed that if the acreage has been offered for lease and not bid on, the energy potential on that acreage is negligible (i.e., industry has screened the tracts offered in that lease sale and found them unpromising).** Or alternatively, it is more important for the surface management agency to offer a previously unoffered tract where the resource potential is the same.

The private response (PR) factor 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. If more than one lease sale was held in the last year, an average estimate is taken to reflect the latest industry response. NC is used to capture the same dimension for lands which have not been offered for lease on a competitive basis. We can construct 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. The average bonus bid for the area is computed as the average of maximum and minimum bids. In principle, BB should be the expected maximum bid per acre in the area if one more acre of land was offered for lease.

AR is a measure of how successful post-lease private activity has been in the area. After a lease has been issued, a tract can be

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* In a more refined model, one should specify the way the land management authority selects the tracts offered for lease within a geothermal area. It is possible, for instance, that the authority leases first the tracts which are most promising from a geological point of view (i.e., the tracts where the probability of successful drilling is higher)--if this is the case, UF would somewhat overestimate the energy potential still available locally for private development.

** Once again, we would need information on industry's behavior to justify this assumption. Moreover, tracts have been reoffered subsequently and leased -- while it is plausible that a tract offered for three or more times and not bid on is not promising, assuming that a tract offered once and not bid on has no energy potential may be too restrictive.

relinquished by the lessee or the lease can be terminated by the leasing agency where the lessee fails to pay the rent or meet other conditions of the leasehold. 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 the relinquishment/termination may be that the tract was leased on a speculative basis or that the investor's acreage limitation has been reached.

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

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

In competitive bidding areas, an environmental assessment by the surface management agency is required before the tracts are offered for lease -- therefore the potential delay from lack of adequate environmental assessments refers to the unoffered portion (if any) of federal acreage in the geothermal area. It should be noted that UU is a measure of the delay incurred in the pre-leasing process rather than a measure of the potential costs and benefits of environmental regulations.* It is possible to develop a measure of potential environmental delay in the post-leasing stage by computing the amount of unleased acreage subject to seasonal or unqualified No Surface Occupancy stipulations. However, the effort required to compile this data is beyond the resources of this project.

Following the fuzzy decision methodology outlined in the Appendix, the composite LAPA indicator is obtained as the intersection of the three main factors. (See Figure 2.)

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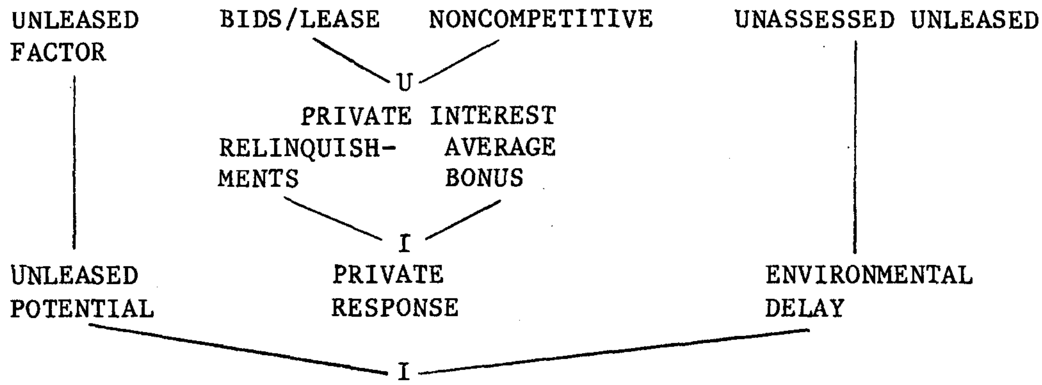
* Environmental delay can also be measured by the number of applications pending in the surface management agencies' district offices or applications rejected for environmental reasons. WAPORA, Inc. is in the process of compiling this data.



LEASING ACTION PRIORITY AREA (LAPA) Figure 2.

Formally, this may be expressed as follows:

LAPA = UF n PR n EF
= UF n (RL n PI n AB) n UU
= UF n (RL n (BL u NC) n AB) n UU.

Or, using the rules to derive a fuzzy indicator,

LAPA(x) = Min [UF(x),AR(x), Max[BL(x),NC(x)], BB(x), UU(x)]

Leasing action priority is high for an area where the unleased factor is high, the private response is high and the potential pre-lease environmental delay is low. Conversely, if any of these factors are unsatisfactory (i.e., if either the unleased factor or the private response factor are low or if the potential delay from environmental factors is high), leasing priority for the area will be lowered.

3. Assigning importance to selected indicators.

The relative importance of each indicator should be reflected in the composite LAPA indicator for each area. In this step, the relevant questions are how should we weight unleased potential versus private response, or bids per lease versus uncompetitive applications as indicators of private interest? We defer the assignment of weights to experts involved in the leasing process but combine their judgements in a systematic way according to fuzzy set rules. The incorporation of experts' judgements on the importance of the various indicators in the construction of the composite LAPA indicator is discussed further below.

4. Constructing the composite indicator.

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

0. Construct the numerical indicators.
1. Characterize indicators by linguistic expressions, such as "high", "low".
2. Modify membership values by importance weights.
3. Combine the indicators using fuzzy set rules for "and" and "or" to obtain LAPA.
4. Display membership values by chromatic scale or gray scale.

This procedure is tested using a sample of 10 KGRAs selected from four western states.

Step 0. Construct the numerical indicators.

Raw indicators are constructed as described in section 2. For the Mono-Long Valley KGRA (CA), we have the following information:

(1) Federal Acreage....................	352,072
(2) Federal Acreage Offered for Lease...	13,715
(3) Federal Acreage Leased..............	5,483
(4) Energy Potential....................	2,100
(5) Number of bids in most recent year..	10
(6) Number of leases in most recent year	1
(7) Total Bonus Bids Accepted ($1000)...	633
(8) Number of Noncompetitive Lease Appl.	6
(9) Acreage Relinquished/Terminated.....	0
(10) Environmentally assessed acreage..	352,072

From these data we derive the numerical indicators:

$$UF = \frac{(1)-(2)}{(1)} \times (4) = \frac{352{,}072 - 13{,}715}{352{,}072} \cdot 2{,}100 = 2{,}018$$

$$BL = (5)/(6) = 10 / 1 = 10$$

$$BB = (7)/(3) = 633{,}000 / 5{,}483 = 115.50$$

$$NC = (8) = 6$$

$$AR = (9)/(3) = 0 / 5{,}483 = 0$$

$$UU = \frac{(1)-(2) - [(10)-(2)]}{(1)-(2)} = \frac{(1)-(10)}{(1)-(2)} = \frac{0}{338{,}357} = 0$$

Step 1. Characterize indicators by linguistic expressions.

The indicators constructed above act as proxy variables for leasing criteria in Figure 2. At this point, analysis can be shifted from the numerical values themselves to broad category terms 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 he needs to recall in "sizing up the situation" for the leasing 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 where judgement is most needed, those areas in the sample where UF is high to some degree, and UU is low to some degree. Unnecessary distinctions within each category can be suppressed where the issue is clear cut, for example where UF is high enough so that the actual value is not of interest.

This is achieved by establishing membership values for the fuzzy sets "high", "low", etc. for each indicator. There are no well established rules to perform this crucial step and much of the literature on fuzzy sets acknowledges that there is considerable amount of subjective judgment in the assignment of grades of membership. In order that the assignment be credible, there are at least two relevant issues to be considered: dependence on context, and robustness.

Context includes the notions of range, distribution, and reference point.* It can vary considerably from one indicator to another, as well as for a single indicator when a different number or different selection of areas is considered, e.g. the range and typical values of reservoir temperatures are higher in Hawaii than in Washington. For a given context, the membership function for "high" is defined so that the grade of membership is 0 below the reference point, is 1 above the upper end point of the range, and rises smoothly from 0 to 1 in between.

Where a typical range and reference point are known a priori, these parameters can be specified by the analyst to determine the membership function. Otherwise, a default procedure is applied to derive these parameters from the sample data set at hand.

The procedure should be robust, so that the typical range and reference point will be stable from one sample to another. In part for this reason, the default reference point is taken to be the median.

It is important to keep in mind that fuzzy sets such as "high" and "low" are defined with respect to a typical or normal range that is in general smaller than the range of a particular sample data set. Thus, "high" for example, is implicitly qualified by a phrase such as "high for a typical value median for a typical range". The range should also be adjusted for robustness by taking into account atypical values, or outliers. A method for identifying outliers and contracting the range accordingly is described in the appendix.

To illustrate, UF in Figure 3 ranges from 3 to 2400, and the

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* See Rips (1980) for a recent study of these and related notions from a psychological perspective, and references to the literature.[10]

distribution is skewed toward smaller values. Expert opinion considers areas with a resource potential of 300 MWe and above as significant for electric power production. The median in our sample is roughly equivalent to this reference point, as values above 274 are considered more and more "high". It is also easy to observe that about half the values are "high" to some (non-zero) degree and half are not characterized at all by "high" (zero degree).

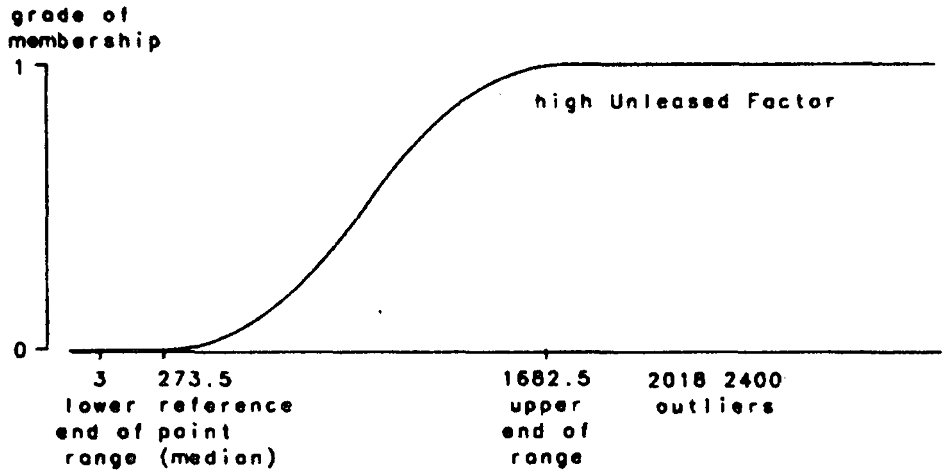

Figure 3. Membership Function Curves for Unleased Factor

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More general linguistic expressions can be formed from primitive terms such as "high" and "low" using logical operators "and", "or", "not" according to fuzzy set rules. As can be seen in Figure 4, "not low" is more inclusive (less restrictive) than "high".

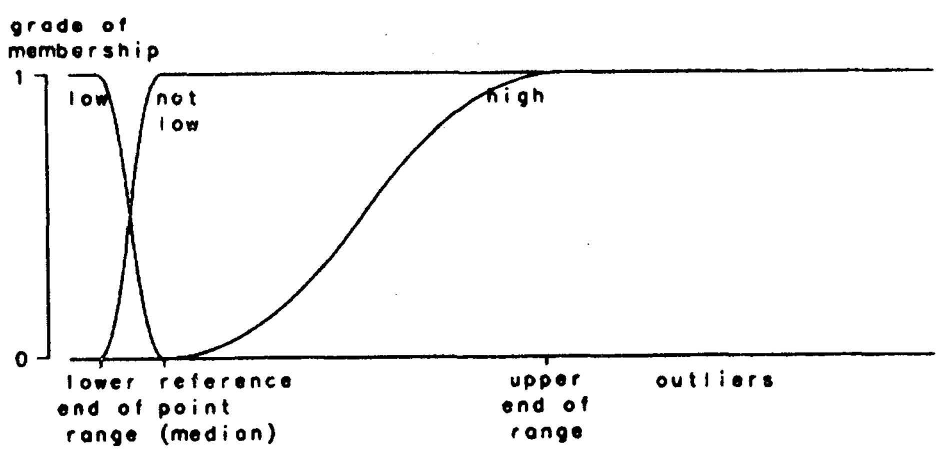

Figure 4. Membership Function Curves for "low", "not low", and "high"

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All values are characterized by "not low" to some (non-zero) degree while only those above the reference point are so characterized by "high". Although the target range for UF, for example, is referred to colloquially as "high", the linguistic expression "not low" is used here instead so that each sample value is assigned some grade of membership for prioritization.

As shown in Figure 4, values below the median have partial membership, while the remaining half all have full membership and so are not distinguished from each other. Detail is preserved where judgment may be needed (below 274) but suppressed where (above 300) the area is of interest per se, and no further evaluation is necessary.

Step 2. <u>Importance weights</u>.

Importance weights are applied to each indicator by raising membership values to a constant power (the importance weight for that indicator).[11] The less important the indicator, the closer to zero is the weight, and the nearer to one is the modified membership value. Raising membership values according to importance helps overcome the effect of poor scores on less important indicators.

Energy potential emerged as the most important factor from our interviews with three experts from the USGS in decisions about leasing priority.* The importance attached to each indicator may also vary with the decisional context for a geothermal resource area. There are three main types of leasing decisions; a KGRA where no land has yet been offered for lease (but some information may be available from surrounding non-competitive areas), areas outside KGRA where no lease applications have been received but some information may be available for neighboring KGRA areas, and areas where leasing activity has already occurred.

The three experts were asked to rank the importance of the six indicators on a scale from 0 to 1. The weight matrix below was obtained:

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* We would like to acknowledge the participation of Messrs. Bruce Hillier, Bruce Blakley, Bob Jaski, and Buford Holt of the Conservation Division, U.S. Geological Survey, Menlo Park.

	UF	BL	BB	NC	AR	EF
EXPERT A						
1st lease in KGRA	1			.9		.9
1st lease outside KGRA	1	.5				.9
Subsequent leases	1	.5	.5	.1	.05	.85
EXPERT B						
1st lease in KGRA	.9			.45		.7
1st lease outside KGRA	.8	.15				.6
Subsequent leases	.8	.7	.7	.20	.5	.6
EXPERT C						
1st lease in KGRA	1			.25		.1
1st lease outside KGRA	1	1				.1
Subsequent leases	1	.66	.66	.33	.66	.1

The simple average of the experts' weights for subsequent leases is the importance weight selected in our example:

	UF	BL	AB	NCL	AR	EF
1st lease in KGRA	.97			.53		.57
1st lease outside KGRA	.93	.55				.53
Subsequent leases	.93	.62	.62	.21	.40	.52

Let us clarify with an example. Assume that KGRA A is characterized by the following membership values (the membership values are computed from the raw indicators as described under Step 1 above).

LABEL	Unleased factor "not low"	Private interest "not low"	Environ delay "low"
Membership value	1	1	.2

In other words, the area has a good energy potential and private developers have shown interest in the area, but there may be delays in completion of environmental assessments.

$$LAPA' = \text{Min}\ \{1,\ 1,\ .2\} = .2$$

If the analyst decides that the potential environmental delay is not that important, he can assign to the environmental delay factor a low importance value, say .10;

$$LAPA'' = \{1,\ 1,\ [.20]^{.10}\} =$$
$$= \{1,\ 1,\ .85\} = .85$$

Comparing LAPA′ and LAPA", we can see that if we take into account the low importance of the potential environmental delay, the leasing priority of the area is increased. The effect of importance, however, is attentuated for categories such as "not low", since half the membership values are 1 and are not changed by raising to a power.

Step 3. <u>Compute the indicator LAPA</u>.

LAPA is computed as the fuzzy union of the three factors. unleased potential (UF), private response (PR), and environmental delay (UU) (see Figure 2):

LAPA(x) = min (UF(x), PR(x), UU(x)) where
PR(x) = min (BB(x), AR(x), BLNC(x)) and
BLNC(x) = max (BL(x), NC(x)).

We reproduce the operations here for the Mono-Long Valley KGRA (see the right side of Figure 3a).

LAPA (Mono-Long Valley) =
= Min [UF, AR, Max (BL, NC), BB, UU]
= Min [1, 1, Max (1, .78), 1, 1] =
= 1.

The complete procedure is summarized in Table 1. Table 2 shows the membership values of the individual indicators for the selected areas. The membership value for the composite LAPA indicator is presented on the left.

Step 4. <u>Display membership values by continuous tone colors</u>.

An experimental computer graphics program available at the Lawrence Berkeley Laboratory is available to interpret linguistic expression, apply importance weights, and display membership values by chromatic scale.[12] A convenient scale for high quality color graphics devices represents 0 through 1 by the continuous range of spectral hues from yellow through orange to red. When color is not available, an achromatic scale from white through gray to black can be substituted instead, as in Figure 5 below.

Table 1. Operation of the Leasing Action Priority Area (LAPA) Indicator

INDICATORS	UNLEASED FACTOR	BIDS PER LEASE	NONCOMPETITIVE LEASES	AVERAGE BONUS	RELINQUISHMENTS/ TERMINATIONS	UNASSESSED/UNLEASED
NUMERICAL VALUES	[460,2018, ..., 700]	[6, 10, ..., NA]	[42, 6, ..., 151]	[215, 116, ..., NA]	[0, 75,..., NA]	[0,0, ...0]
MEMBERSHIP LABEL	Not Low	Not Low	Not Low	Not Low	Not High	Not High
MEMBERSHIP VALUES	$\left\{\frac{UF(x_1)}{x_1}, \ldots, \frac{UF(x_{10})}{x_{10}}\right\}$	$\left\{\frac{BL(x_1)}{x_1}, \ldots, \frac{BL(x_{10})}{x_{10}}\right\}$	$\left\{\frac{NC(x_1)}{x_1}, \ldots, \frac{NC(x_{10})}{x_{10}}\right\}$	$\left\{\frac{BB(x_1)}{x_1} \ldots, \frac{BB(x_{10})}{x_{10}}\right\}$	$\left\{\frac{AR(x_1)}{x_1}, \ldots, \frac{AR(x_{10})}{x_{10}}\right\}$	$\left\{\frac{UU(x_1)}{x_1}, \ldots, \frac{UU(x_{10})}{x_{10}}\right\}$
IMPORTANCE	I = 1 or .9	I = 1 or .6	I = 1 or .15	I = 1 or .6	I = 1 or .28	I = 1 or .10
MODIFIED MEMBERSHIP VALUES	$\left\{\frac{UF(x_1)^I}{x_1}, \ldots, \frac{UF(x_{10})^I}{x_{10}}\right\}$	$\left\{\frac{BL(x_1)^I}{x_1}, \ldots, \frac{BL(x_{10})^I}{x_{10}}\right\}$	$\left\{\frac{NC(x_1)^I}{x_1}, \ldots, \frac{NC(x_{10})^I}{x_{10}}\right\}$	$\left\{\frac{BB(x_1)^I}{x_1}, \ldots, \frac{BB(x_{10})^I}{x_{10}}\right\}$	$\left\{\frac{AR(x_1)^I}{x_1}, \ldots, \frac{AR(x_{10})^I}{x_{10}}\right\}$	$\left\{\frac{UU(x_1)^I}{x_1}, \ldots, \frac{UU(x_{10})^I}{x_{10}}\right\}$

UNION

BIDS PER LEASE (Not Low) <u>OR</u> NONCOMPETITIVE LEASES (Not Low)

$$\frac{BLNC(x_i)}{x_i} = \left\{\frac{\text{Max}\left[BL(x_i)^I, NC(x_i)^I\right]}{x_i}\right\}$$

= PRIVATE INTEREST (Not Low)

INTERSECTION

UNLEASED FACTOR (Not Low) <u>AND</u> PRIVATE INTEREST (Not Low) <u>AND</u> AVERAGE BONUS (Not Low) <u>AND</u> RELINQUISHMENTS/TERMINATIONS (Not High) <u>AND</u> ENVIRONMENTAL DELAY (Not High)

= LAPA HIGH

$$\frac{CI(x_i)}{x_i} = \frac{\text{Min } UF(x_i)^I, BLNC(x_i), BB(x_i)^I, AR(x_i)^I, UU(x_i)^I}{x_i}$$

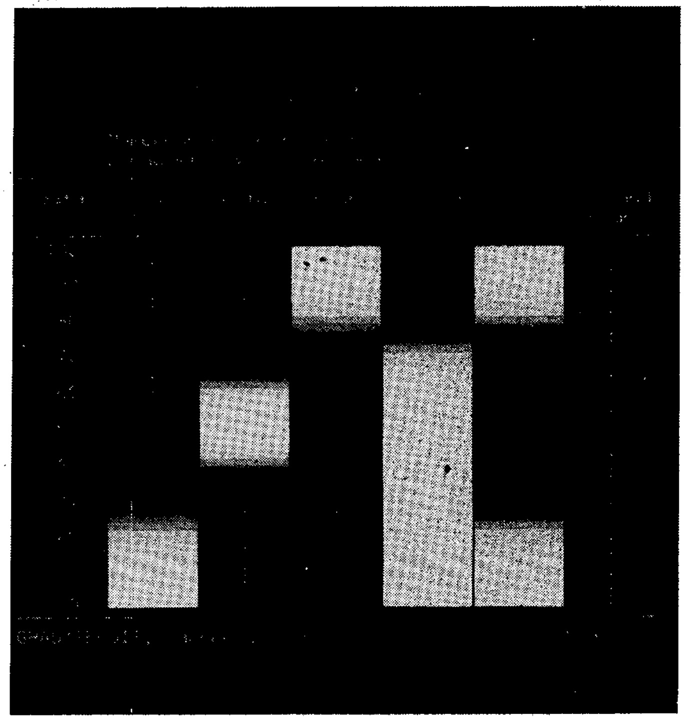
Table 2. Membership Values for LAPA Indicators

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	1.00	.84	1.00
1.00	OR Newberry	1.00		1.00		1.00

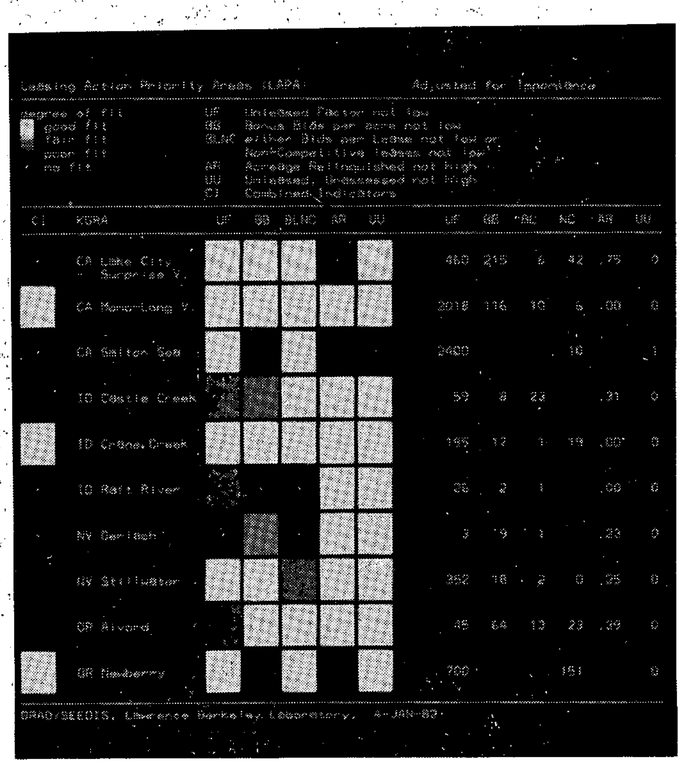
Adjusted for Importance

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		.87		.00
.08	ID Castle Creek	.08	.30	1.00	.99	1.00
.80	ID Crane Creek	.80	1.00	1.00	1.00	1.00
.00	ID Raft River	.01	.00	.00	1.00	1.00
.00	NV Gerlach	.00	.50	.00	1.00	1.00
.25	NV Stillwater	1.00	1.00	.25	1.00	1.00
.04	OR Alvord	.04	1.00	1.00	.93	1.00
1.00	OR Newberry	1.00		1.00		1.00

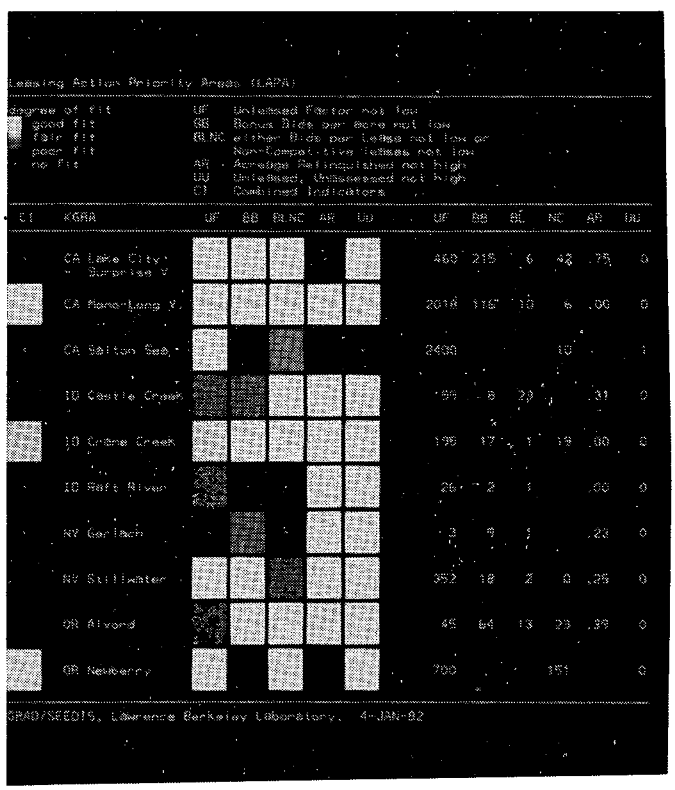


The degree of membership of each area in the set "Lease Action Priority High" is displayed in Figure 6 and Figure 7 using the chromatic scale. If we consider the output of Run 1 (Figure 6), the leasing priority is easily read off as follows: Mono-Long Valley, Crane Creek, and Newberry are high priority, Stillwater, Castle Creek, and Alvord follow, Stillwater being higher priority: and Lake City-Surprise Valley, Salton Sea, Gerlach, and Rath River are low priority. This is the case when all 5 criteria must be satisfied and no tradeoffs are permitted.*

* However, the analyst or surface land manager may be willing to give up one objective for a better fit to the rest, or be happy with areas meeting 4 out of 5 criteria. Lake City-Surprise Valley will have high priority if acreage relinquished is not considered an important criterion. Stillwater and Alvord will also qualify as having high priority if meeting 4 out of 5 criteria is considered sufficient.



In Run 2 (Figure 7), the default option for importance makes all weights equal to 1, and the degree of membership is slightly weakened for Crane Creek, Gerlach, Salton Sea, and Alvord, although the ranking remains essentially the same.



5. Conclusions

There is no unique set of priority indicators and importance weights appropriate to all leasing decisions. The composite LAPA indicator is a planning and decision-support tool which utilizes automated procedures to organize information in a format that reduces the analyst's cognitive load. Data is sorted according to how well it matches a given set of leasing decision criteria, and unnecessary numerical precision is dispensed with. LAPA accomodates the need of the policy analyst to adapt weights and choice of indicators for prioritization of geothermal areas to specific decision environments. Both the clear-cut match and cases having different degrees of fit are easily summed up by color graphics which allows the decision maker to make almost spontaneous visual tradeoffs between objectives. The ideal of cognitive economy information systems is served by giving the decision-maker access to better summary information with less effort.

We have focused on the case of subsequent lease sales in a KGRA, and it should be noted that the choice of importance weights and indicators will differ if the first lease is being offered at or outside a KGRA. In addition, other exogenous indicators may be worth consideration in specific institutional contexts. If employment problems are pressing and geothermal development is related to job provision, a priority index could certainly include some "unemployment is high" label. Other indicators of regional distress could be included so that the leasing decisions take into account regional economic targets in addition to national energy production needs. It could also happen that environmental factors that are negligible from a federal standpoint are of critical importance locally.

Secondly, LAPA is a hierarchical structuring process and should be used as an iterative procedure. A new analysis should be carried out after each series of leasing decisions because the numerical values of the indicators and ultimately the rankings of the geothermal areas will be affected by the leasing decisions themselves. Sensitivity analysis can be implemented by setting different thresholds for the membership function.

In this context, simple simulations for policy analysis can be performed using the GRAD/SEEDIS fuzzy set programs. It would be easy, for instance, to rerun the program assuming that all the land in the highest priority areas has been offered for lease, in order to have an idea of what the next leasing priority would be if such a policy was to be implemented.

In summary, the composite LAPA indicator can support analysis of leasing data and improve the success of leasing decisions. The flexibility of this decision tool is enhanced by the availability of a computerized data base utilizing fuzzy set software and graphical displays.

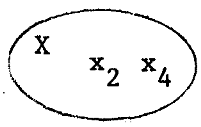
Appendix

FUZZY SET THEORY [2,11]

MEMBERSHIP IN A FUZZY SET

In traditional set theory, we define sets and objects (or elements) of a universe of discussion. These objects may either belong or not belong to the set in question.

Ex.1: The set X is the set of females in a family of four (father [x_1], mother [x_2], son [x_3], daughter [x_4]). Our universe is composed of four elements, two of which belong to the set X.



$x_1 \quad x_3 \qquad X = \left\{x_2,\ x_4\right\}$

Each of the elements is either a member of X or not.

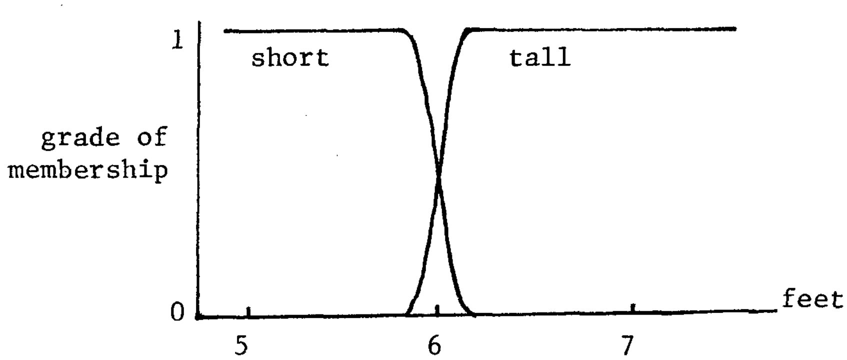
The essential idea in fuzzy set theory is to associate to each element of the universe of discussion a degree of membership: a number between 0 and 1. "The more" an element belongs to a set, the higher the value of the degree of membership.

A fuzzy set is characterized by a membership function associated to each element of the set. If A is a fuzzy set, the following notation is used:

$$A = \left\{\frac{A(x_1)}{x_1},\ \frac{A(x_2)}{x_2},\ \ldots,\ A\frac{(x_n)}{x_n} = \frac{A(x)}{x}\right\}$$

where $A(x_i)$ is the degree of membership of x_i.

Ex. 2: The universe of discourse over which a membership function is defined can be continuous, as in the relationship between height measured in feet and being "tall" or "short". In this case, "tall" and "short" are fuzzy sets defined on positive numbers.



FUZZY SET OPERATIONS

Fuzzy set can be defined in several ways that are equivalent to the linguistic expressions "or", "and", and "not". Assume A and B are fuzzy sets defined on x with membership A(x), B(x).

a. Union

The union of two fuzzy sets A and B is denoted by AUB and can be interpreted as the set labeled by "A or B or both". In symbols, we have

$$A \cup B = \left\{ \frac{\text{Max } A(x), B(x)}{x} \right\}$$

where Max {A(x), B(x)} denotes the maximum of the two values.

Ex. 3: Let x_1, x_2 and x_3 be three managers for a plant. Let A be the fuzzy set of experienced managers and B the fuzzy set of educated managers. We can also say that the label "is an experienced manager" is associated to the fuzzy set A and the label "is an educated manager" is associated to the fuzzy set B. Let the membership functions be

$$A(x_i) = \left\{ \frac{.4}{x_1}, \frac{.5}{x_2}, \frac{.8}{x_3} \right\}$$

$$B(x_i) = \left\{ \frac{.9}{x_1}, \frac{.6}{x_2}, \frac{.5}{x_3} \right\},$$

Let us assume that we are interested in the fuzzy set of "experienced <u>or</u> educated managers". In order to construct it, we need only apply the fuzzy union operation:

$$A \cup B = \left\{ \frac{\text{Max } (.4,\ .9)}{x_1}, \frac{\text{Max } (.5,\ .6)}{x_2}, \frac{\text{Max } (.8,\ .5)}{x_3} \right\}$$

$$= \left\{ \frac{.9}{x_1}, \frac{.6}{x_2}, \frac{.8}{x_3} \right\}$$

b. Intersection

The intersection of two fuzzy sets A and B is a fuzzy set denoted by A∩B, whose membership function is the minimum of each corresponding membership value. Formally, we have

$$A \cap B = \left\{ \frac{\text{Min } A(x), B(x)}{x}, \right\}$$

where Min {A(x), B(x)} denotes the minimum of the two values.

Ex. 4: Let x, x_2, x_3 be the three managers defined in Ex. 4. Assume we are interested in the set of "experienced and educated managers". Applying fuzzy intersection

$$A \cap B = \left\{\frac{\text{Min }(.4,\ .9)}{x_1},\ \frac{\text{Max}(.5,\ .6)}{x_2},\ \frac{\text{Max }(.8,\ .5)}{x_3}\right\}$$

$$= \left\{\frac{.4}{x_1},\ \frac{.5}{x_2},\ \frac{.5}{x_3}\right\}.$$

c. Negation

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

$$\text{not } A = \left\{\frac{1 - A(x)}{x}\right\}.$$

Ex. 5: Let us consider the set A of experienced managers as defined in the previous examples. The set Not A, or the "not experienced managers" is

$$\text{set } A = \left\{\frac{1 - .4}{x_1},\ \frac{1 - .5}{x_2},\ \frac{1 - .8}{x_3}\right\} = \left\{\frac{.6}{x_1},\ \frac{.5}{x_2},\ \frac{.2}{x_3}\right\}$$

Note that x_3, who is the most experienced in the group, has now the lowest membership value in set of nonexperienced managers.

d. Importance

The importance of a fuzzy set is captured by a positive number I, which can assume values between 0 and infinity. The "importance" operation acts as a membership function modifier -- if the importance of belonging to set A is I, the membership function is modified as follows:

$$A^I = \left\{\frac{[A(x)]^I}{x}\right\}.$$

Note that if the importance index is 1, the membership function is not changed by the operation. If I is very high, only the elements that belong "strongly" in the set (i.e., with degree of membership close to 1) maintain a high degree of membership after the operation.

If I is low (less than 1), degrees of membership increase for all the elements of the set. In particular, for I=0 (absolutely unimportant) the degree of membership is 1 for all the elements in the set.

Ex. 6 - Let B be the set of educated managers. If education is of very low importance, say x = 0.05, then

$$B^I = B^{0.05} = \left\{\frac{(.9)^{0.05}}{x_1}, \frac{(.6)^{0.05}}{x_2}, \frac{(.5)^{0.05}}{x_3}\right\}$$

$$= \left\{\frac{.99}{x_1}, \frac{.99}{x_2}, \frac{.99}{x_3}\right\}$$

If education is irrelevant, all three managers belong to the set to a similar degree. The membership in the set is made less restrictive. If education is of high importance, say x=3, then

$$B^I = B^3 = \left\{\frac{(.9)^3}{x_1}, \frac{(.6)^3}{x_2}, \frac{(.5)^3}{x_3}\right\}$$

$$= \left\{\frac{.73}{x_1}, \frac{.22}{x_2}, \frac{.13}{x_3}\right\}.$$

Therefore, the membership is made more restrictive, and only x_1 who is the better educated to start with, maintains a high degree of membership in the set.

DECISION MAKING USING FUZZY SETS

If X is a set of alternatives and A,B,C ... are fuzzy sets denoting goals or constraints, then the decision membership function $U_o(x)$ is the intersection of the fuzzy sets

$$U_o(x) = A \cap B \cap C \ldots$$

$$= \text{Min } \{A(x), B(x), C(x) \ldots\}$$

and can be interpreted as the degree to which each of the alternatives satisfies the constraints and goals.

Ex. 7: Assume that we have to hire a manager and that we want the person to be experienced and educated (these are the fuzzy constraints on our choice). Then from Ex. 5, the decision membership function is

$$U_o(x) = A \cap B = \left\{\frac{.4}{x_1}, \frac{.5}{x_2}, \frac{.5}{x_3}\right\}$$

so that the most satisfying choices seem to be managers x_2 and x_3.

Assume now that we are primarily interested in an experienced person and that education is not that important, say I=0.2. In this case:

$$U_o x = A \cap B^{0.2}$$

$$= \left\{ \frac{\text{Min } (.4,\ .98)}{x_1}, \frac{\text{Min } (.5,\ .90)}{x_2}, \frac{\text{Min } (.8,\ .87)}{x_3} \right\}$$

$$= \left\{ \frac{.4}{x_1}, \frac{.5}{x_2}, \frac{.8}{x_3} \right\}$$

Now the alternative with the highest decision membership value is x_3 (who is indeed the most experienced of the group).

In the GRAD/SEEDIS software programs, membership functions for "high" and "low" are defined in terms of two parameters; reference point and range. As described in Section 2, the median is chosen to be the reference point. The default procedure to determine a robust range from a sample data set is as follows:

First, the central portion of the sample is determined from the first and third quartiles (q1 and q3). This portion is then extended toward, but not beyond, the sample minimum (smin) and maxium (smax) on either side by a chosen factor (1.5) times the extent of the central portion.

<lower end of robust range> = max (smin, q1 - 1.5 (q3-q1))

<upper end of robust range> = min (smax, q3 + 1.5 (q3-q1))

By definition, outliers are considered to be those values outside the robust range. Taking 1.5 as the factor would exclude about 1% of a normal sample.[13]

For example, consider the ten values for UF in Figure A. There the median is (195 + 352)/2 = 273.5; q1 = 45 since 10/4 values are smaller than 45; and similarly q3 = 700. The robust range is:

[max (3, 45-1.5(700-45)), min (2400, 700+1.5(700-45))]
= [3, 1682.5],

leaving 2018 and 2400 as outliers.

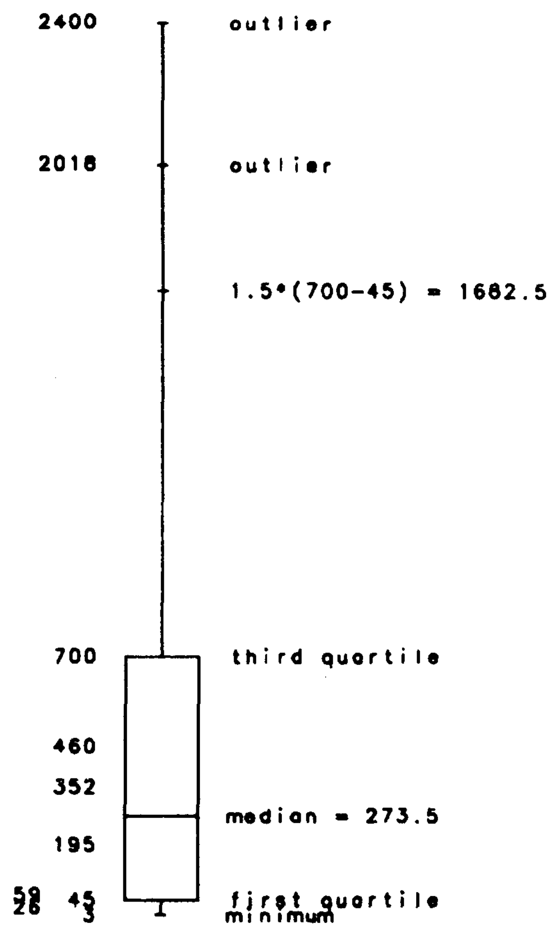


Figure A. Sample Distribution for Unleased Factor

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