APPENDIX A
THE ANALYTICAL PROCESS AND THE EXPERT CHOICE MERCURY RETIREMENT MODEL

THE ANALYTIC HIERARCHY PROCESS

The analytic hierarchy process (AHP), developed at the Wharton School of Business by Thomas Saaty, allows decision makers to model a complex problem in a hierarchical structure showing the relationships of the goal, objectives (criteria), sub-objectives, and alternatives as show in Figure A-1. Uncertainties and other influencing factors can also be included.

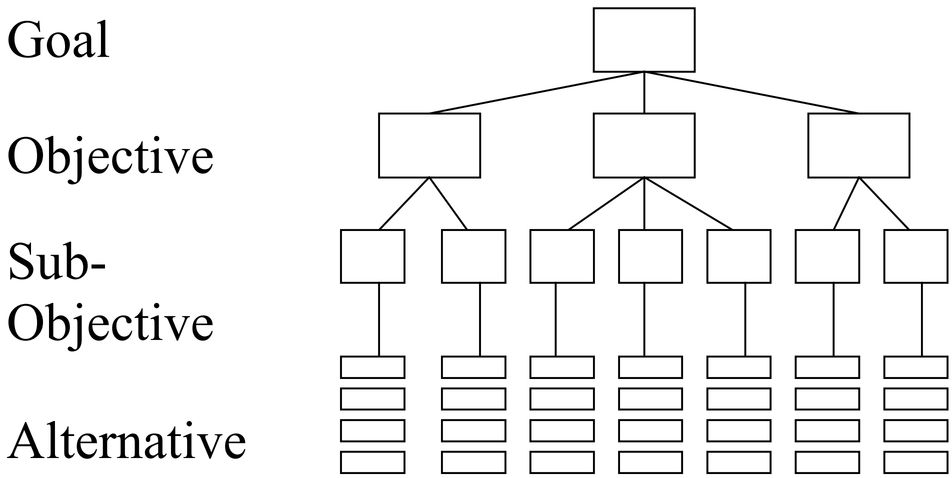


Figure A-1 Decision Hierarchy

AHP allows for the application of data, experience, insight, and intuition in a logical and thorough way. AHP enables decision-makers to derive ratio scale priorities or weights as opposed to arbitrarily assigning them. In doing so, AHP not only supports decision-makers by enabling them to structure complexity and exercise judgment, but also allows them to incorporate both objective and subjective considerations in the decision process. AHP is a compensatory decision methodology because alternatives that are deficient with respect to one or more objectives can compensate by their performance with respect to other objectives. AHP is composed of several previously existing, but unassociated concepts and techniques such as hierarchical structuring of complexity, pairwise comparisons, redundant judgments, and the Eigenvector method for deriving weights, and consistency considerations. Although each of these concepts and techniques were useful in and of themselves, Saaty's synergistic combination of the concepts and techniques along with some new developments produced a process whose power is indeed far more than the sum of its parts (Formar and Selly, Undated).

One of the major benefits of AHP is that the theory does not demand perfect consistency. AHP allows inconsistency, but provides a measure of the inconsistency in each set of judgments. This inconsistency measure is an important by-product of the process of deriving priorities based on pairwise comparisons. Being consistent is often thought of as a prerequisite to clear thinking. However, the real world is hardly ever perfectly consistent. Another reason for inconsistency is lack of information about the factors being compared. An inconsistency ratio of about 10% or less is usually considered acceptable. With the model developed for mercury retirement options, consistency ratios of 0-6% were achieved.

AHP is built on a solid yet simple theoretical foundation based on three basic principles: decomposition, comparative judgments, and hierarchic composition or synthesis of priorities. The decomposition principle is applied to structure a complex problem into a hierarchy of clusters, sub-clusters, and so on. The principle of comparative judgments is applied to construct pairwise comparisons of all combinations of elements in a cluster with respect to the parent of the cluster. These pairwise comparisons are used to derive "local" priorities of the elements in a cluster with respect to their parent. The principle of hierarchic composition of synthesis is applied to multiply the local priorities of elements in a cluster by the "global" priority of the parent element, producing global priorities for the lowest level elements (the alternatives) (Saaty, 1980).

All theories are based on axioms. The simpler and fewer the axioms, the more general and applicable is the theory. Originally, AHP was based on three relatively simple axioms. The first axiom, the reciprocal axiom, requires that if $P_C(E_A, E_B)$ is a paired comparison of elements A and B with respect to their parent, element C, representing how many times more element A possesses a property than does element B, then $P_C(E_B, E_A) = 1/P_C(E_A, E_B)$. For example, if A is 5 times larger than B, then B is one fifth as large as A.

The second, or homogeneity axiom, states that the elements being compared should not differ by too much, else there will tend to be larger errors in judgment. When constructing a hierarchy of objectives, one should attempt to arrange elements in a cluster so that they do not differ by more than an order of magnitude. (The AHP verbal scale ranges from 1 to 9, or about an order of magnitude. The numerical and graphical modes of Expert Choice accommodate almost two orders of magnitude, allowing a relaxation of this axiom. Judgments beyond an order of magnitude generally result in a decrease in accuracy and increase in inconsistency).

The third axiom states that those judgments about, or the priorities of, the elements in a hierarchy do not depend on lower level elements. This axiom is required for the principle of hierarchic composition to apply. While the first two axioms are always consonant with real work applications, this axiom requires careful examination, as it is not uncommon for it to be violated.

A fourth axiom, introduced later by Saaty, says that individuals who have reasons for their beliefs should make sure that their ideas are adequately represented for the outcome to match these expectations. While this axiom might sound a bit vague, it is very important because the generality of AHP makes it possible to apply AHP in a variety of ways and adherence to this axiom ensures the application AHP in appropriate ways.

Most mathematicians will agree that the simplest of two or more competing theories is preferable. As discussed above, the axioms behind AHP are simple. This simplicity and the ratio scale measures that AHP produces make it a powerful decision theory.

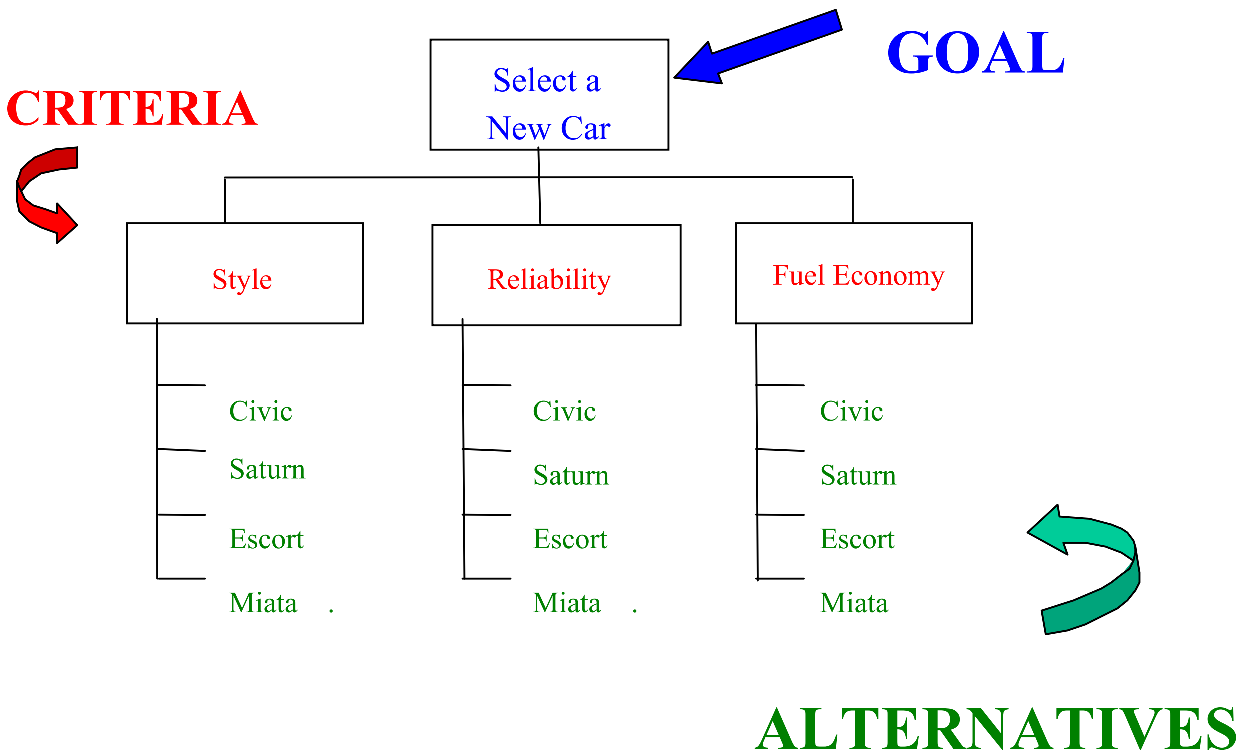
MATHEMATICS OF AHP

The following example of the decision making process behind buying a new car illustrates AHP and the associated mathematics used to derive weights and priorities (TASC, Undated). An approximation to the Eignevector method suitable for hand calculations is used. While this approximation is reasonable when the judgements are consistent, it may not be so for inconsistent judgements and is therefore not recommended unless a computer and software are available.

The first three steps are to:

- State the Goal:
  - Select a New Car
- Define the Criteria (or Objectives)
  - Style (i.e., want a good looking car)
  - Reliability (i.e., want a reliable car)
  - Fuel Economy (i.e., want a fuel efficient car)
- Identify the Alternatives:
  - Civic Coupe
  - Saturn Coupe
  - Ford Escort
  - Mazda Miata

This information is then arranged in a hierarchical tree as follows:



To determine the relative importance or ranking of the criteria or objectives by making judgements using the established scale below:

1 Equal 3 Moderate 5 Strong 7 Very Strong 9 Extreme

Thus, one possible outcome of a brainstorming sessions would be that:

1. Reliability is 2 times as important as style
2. Style is 3 times as important as fuel economy

3. Reliability is 4 times as important as fuel economy

This can be expressed as a matrix

	Style	Reliability	Fuel Economy
Style	1/1	1/2	3/1
Reliability	2/1	1/1	4/1
Fuel Economy	1/3	1/4	1/1

To get a ranking of priorities from a pair wise matrix, Eigenvectors are used. The Eigenvector solution was demonstrated mathematically as the best approach by Dr. Saaty. To solve for the Eigenvector:

1. In successive calculations, square the matrix.
2. The row sums are then calculated and normalized
3. Stop when the difference between these sums in two consecutive calculations is smaller than a prescribed value

First convert the fractions to decimals so that standard matrix algebra can be used:

	Style	Reliability	Fuel Economy
Style	1.0000	0.5000	3.0000
Reliability	2.0000	1.0000	4.0000
Fuel Economy	3.0000	0.2500	1.0000

Step 1. Square the matrix, using standard rules of matrix

$$\begin{bmatrix} 1.0000 & 0.5000 & 3.0000 \\ 2.0000 & 1.0000 & 4.0000 \\ 3.0000 & 0.2500 & 1.0000 \end{bmatrix} \quad \text{times} \quad \begin{bmatrix} 1.0000 & 0.5000 & 3.0000 \\ 2.0000 & 1.0000 & 4.0000 \\ 3.0000 & 0.2500 & 1.0000 \end{bmatrix}$$

so that, for example, (1.0000 * 1.0000) + (0.50000 * 2.0000) + (3.0000* 0.3333) = 3.0000 gives the first entry in the squared matrix, which is as follows:

$$\begin{bmatrix} 3.0000 & 1.7500 & 8.0000 \\ 5.3332 & 3.0000 & 14.0000 \\ 1.1666 & 0.6667 & 3.0000 \end{bmatrix}$$

Step 2. Compute the first Eigenvector

First, sum the rows,

$$\begin{bmatrix} 3.0000 & + & 1.7500 & + & 8.0000 \\ 5.3332 & + & 3.0000 & + & 14.0000 \\ 1.1666 & + & 0.6667 & + & 3.0000 \end{bmatrix} \begin{matrix} = & 12.7500 \\ = & 22.3332 \\ = & 4.8333 \end{matrix}$$

Next sum the row totals (i.e., 12.7500 + 22.3332, + 4.8333 = 39.9165), and then normalize by dividing the row sum by the row totals.

12.7500/39.9165	=	0.3194
22.3332/39.9165	=	0.5595
4.8333/39.9165	=	0.1211
		1.0000

The result is our Eigenvector:

$$\begin{bmatrix} 0.3194 \\ 0.5595 \\ 0.1211 \end{bmatrix}$$

This process must be iterated until the Eigenvector solution does not change from the previous iteration. Therefore, continuing the example, again we square our resulting matrix from the first iteration (step 1).

$$\begin{bmatrix} 3.0000 & + & 1.7500 & + & 8.0000 \\ 5.3332 & + & 3.0000 & + & 14.0000 \\ 1.1666 & + & 0.6667 & + & 3.0000 \end{bmatrix}$$

which results in

$$\begin{bmatrix} 27.6653 & + & 15.8330 & + & 72.4984 \\ 48.3311 & + & 27.6662 & + & 126.6642 \\ 10.5547 & + & 6.0414 & + & 27.6653 \end{bmatrix}$$

Next compute the Eigenvector (step 2):

$$\begin{bmatrix} 27.6653 & + & 15.8330 & + & 72.4984 \\ 48.3311 & + & 27.6662 & + & 126.6642 \\ 10.5547 & + & 6.0414 & + & 27.6653 \end{bmatrix} \begin{matrix} = & 115.9967 & 0.3196 \\ = & 202.6615 & 0.5584 \\ = & 44.2612 & 0.1220 \\ & 362.9196 & 1.0000 \end{matrix}$$

Finally, compute the difference between the previously computed Eigenvector and this one:

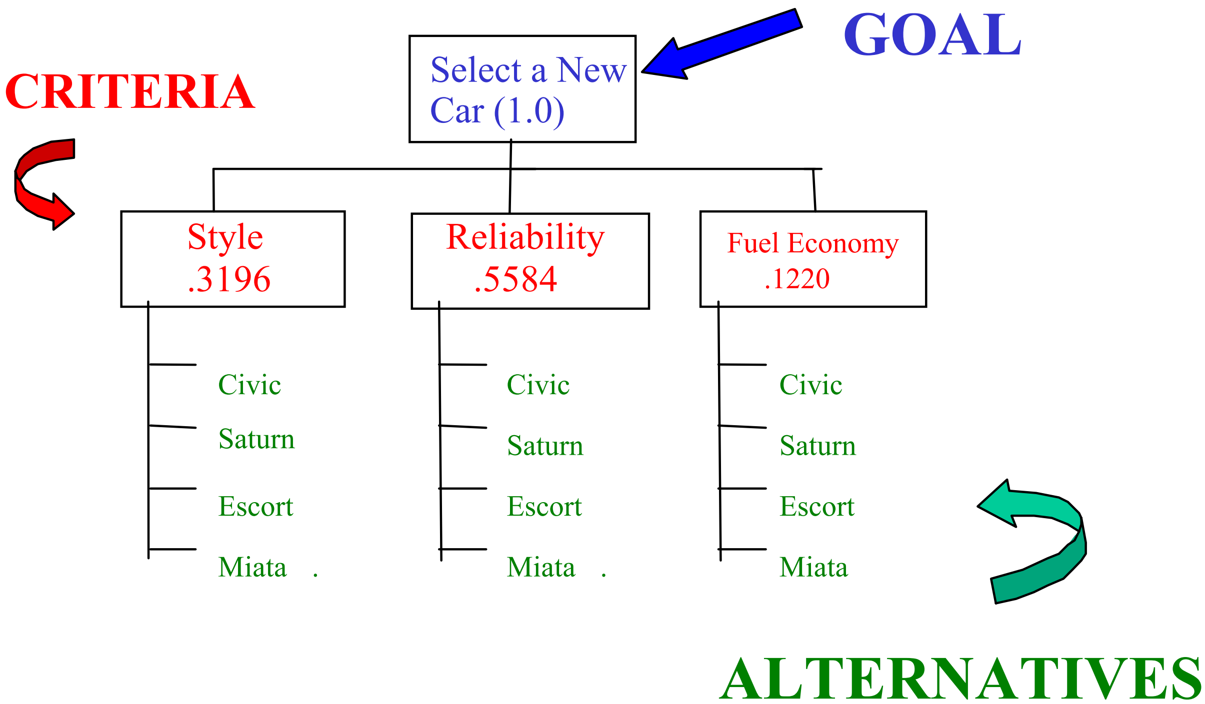
$$\begin{bmatrix} 0.3194 \\ 0.5595 \\ 0.1211 \end{bmatrix} - \begin{bmatrix} 0.3196 \\ 0.5584 \\ 0.1220 \end{bmatrix} = \begin{bmatrix} -0.0002 \\ 0.0011 \\ -0.0009 \end{bmatrix}$$

This process should be continued until there is no difference to four decimal places. Although it is helpful to understand the mathematics behind the decision theory, it is not necessary to know how to do the calculations as Expert Choice, does all the calculations automatically.

The computed Eigenvector provides us the relative ranking of our criteria or objectives. Using the second computed Eigenvector as an example,

Style	0.3196	←	The second most important criterion
Reliability	0.5584	←	The most important criterion
Fuel Economy	0.1220	←	The least important criterion

Going back to our hierarchical tree, our weights would be shown as follows:



Next, the same type of pairwise comparisons would be performed for each of the alternatives. For example, in terms of style, pairwise comparisons determines the preferences of each alternative over another:

	Civic	Saturn	Escort	Miata
Civic	1/1	1/4	4/1	1/6
Saturn	4/1	1/1	4/1	1/4
Escort	1/4	1/4	1/1	1/5
Miata	6/1	4/1	5/1	1/1

Following the above steps, the Eigenvector would be computed to determine the relative ranking of alternatives, namely:

Civic	.1160
Saturn	.2470
Escort	.0600
Miata	.5770

The Eigenvector and ranking of alternatives for reliability would be accomplished the same way. Since AHP can combine both qualitative and quantitative information, fuel economy information in miles per gallon for each alternative would be obtained and normalized to allow it to be used with the other rankings as shown below.

Civic	34	34/113	=	.3010
Saturn	27	27/113	=	.2390
Escort	24	24/113	=	.2120
Miata	28	28/113	=	.2480
	113			1.0000

The populated hierarchical tree with all the weights is shown on the following page. To derive the solution, matrix algebra is used one more time to multiply the alternative weights by the criteria weights.

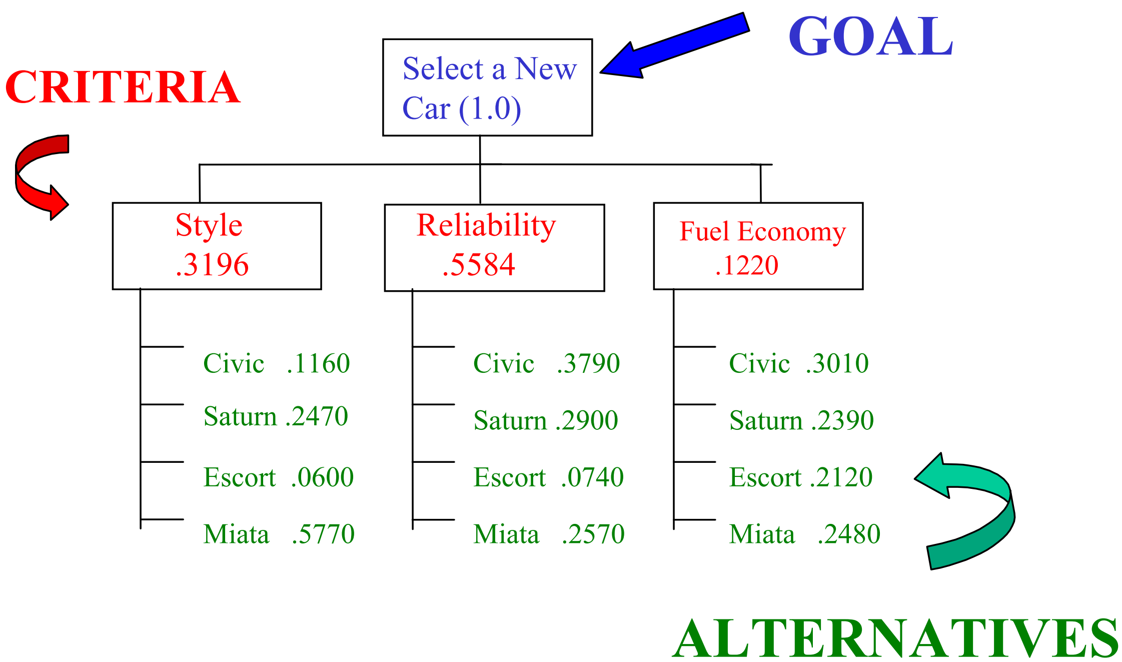
	Style	Reliability	Fuel Economy
Civic	.1160	.3790	.3010
Saturn	.2470	.2900	.2390
Escort	.0600	.0740	.2120
Miata	.5770	.2570	.2480

*

Criterion	
.3196	Style
.5584	Reliability
.1220	Fuel Economy

=

Civic	.3060
Saturn	.2720
Escort	.0940
Miata	.3280



The end results show that the Miata is the best choice for the stated criteria based on the highest ranking of .3280. Of course costs were not included. Although costs could have been included, in many complex decisions, costs should be set aside until the benefits of the alternatives are evaluated. Discussing costs together with benefits can sometimes bring forth many political and emotional responses. There are several ways to handle benefits and costs to include:

1. Graphing benefits and costs of each alternative and chose the alternative with the lowest cost and highest benefit.

2. Benefit to cost ratios
3. Linear programming
4. Separate benefit and cost hierarchical trees and then combine the results

Using the benefits to cost ratios for the simple car example, the Civic would then become the best choice.

	Cost	Normalized Costs	Benefit to Cost Ratios		
1. Miata	$18,000	.3333	.3280/.3333	=	.9840
2. Civic	$12,000	.2222	.3060/.2222	=	1.332
3. Saturn	$15,000	.2778	.2720/.2778	=	.9791
4. Escort	$9,000	.1667	.0940/.1667	=	.5639
	$54,000	1.000			

EXPERT CHOICE

Expert Choice was developed in 1983 and as of 1995, was being used by major Fortune 100 companies such as IBM, Ford, General Electric and Rockwell; numerous government agencies to include the FAA, VA, GSA, the U.S. Navy, and the U.S. Air Force; and in 57 countries throughout the world. The list of commercial and government users and sponsors continues to grow today as AHP gains wider understanding and acceptance. Expert Choice automates the analytic hierarchy process and calculates all of the mathematical computations detailed in the earlier section. It provides an easy to use graphical interface for structuring the decision problem as a hierarchy and deriving ratio scales measures through pairwise relative comparisons.

The pairwise comparison process can be performed in Expert Choice using words, numbers, or graphical bars, and typically incorporates redundancy, which results in a reduction of measurement error as well as producing a measure of consistency of the comparison judgments. Humans are much more capable of making relative rather than absolute judgments. The use of redundancy permits accurate priorities to be derived from verbal judgments even though the words themselves are not very accurate. Therefore, words can be used to compare qualitative factors and derive ratio scale priorities that can be combined with quantitative factors. In addition, Expert Choice allows the conduct of sensitivity analysis. Sensitivity analysis allows the investigation of the effect on the optimal solution or ranking if the objectives or criteria take on other possible values or weights. Usually there are some parameters that can be assigned any reasonable value without affecting the optimality of the solution. However, there may also be parameters with likely values that would yield a new optimal solution. Therefore, the basic objective of sensitivity analysis is to identify these particularly sensitive parameters so that special care can then be taken in estimating them more closely and in selecting a solution which performs well for most of their likely values.

The steps in applying AHP and Expert Choice to a decision problem include:

Step 1: Problem identification and research

1a) Problem identification
1b) Identify objectives and alternatives. A list of the pros and cons of each alternative is often helpful in identifying the objectives

1c) Research the alternatives

Step 2: Eliminate infeasible alternatives

2a) Determine the "musts"
2b) Eliminate alternatives that do not meet the "musts"

Step 3: Structure a decision model in the form of a hierarchy to include goal, objectives (and sub objectives), and alternatives. Add other relevant factors (such as scenarios) as required.

Step 4: Evaluate the factors in the model by making pairwise relative comparisons

4a) Use as much factual data as is available, but interpret the data as it relates to to satisfying the objectives (i.e., do not assume a linear utility curve without thinking about whether it is a reasonable assumption)
4b) Use knowledge, experience, and intuition for these qualitative aspects of the problem or when no hard data is available

Step 5: Synthesize to identify the "best" alternative. Once judgments are entered for each part of the model, the information is synthesized to achieve an overall preference. The synthesis ranks the alternatives in relation to the goal.

Step 6: Examine and verify decision, iterate as required.

6a) Examine the solution and perform sensitivity analyses. If the solution is sensitive to factors in the model for which accurate data are not available, consider spending the resources to collect the necessary data and iterate back to step 4.
6b) Check the decision against intuition. If they do not agree, ask why intuition suggests that a different alternative is best. See if the reason is already in the model. If not, revise the model (and or judgements). Iterate as required. In general both model and intuition may change as more information about the problem becomes available.

Step 7: Document the decision for justification and control.

MERCURY RETIREMENT MODEL

The model was developed using the Expert Choice software following the steps identified above and using the expertise of SAIC engineers and analysts. The hierarchical model is comprised of a goal, several levels of objectives (or criteria), and rating intensities or scales for the alternatives that were identified. Two modes are available within Expert Choice for prioritizing alternatives: relative measurement and absolute measurement. When a model is created based on relative measurement, the priorities of the objectives, sub-objectives and alternatives are computed by comparing the elements to each other. If there is a large number of alternatives (from 10 to thousands), which is the case with this specific mercury refinement problem, the pairwise comparison process can become overwhelming.

In contrast, absolute measurement gauges elements against an established scale, thereby reducing the volume of comparisons. In Expert Choice, absolute measurement is performed in a Ratings spreadsheet that is incorporated into the software. The objectives and sub-objectives are pairwise compared against one another, but the alternatives are compared against a pre-established scale.

While some scales such as cost (e.g. dollars) and measurement (e.g., tons, milligrams, etc.) are well established and widely recognized, other scales can be customized for the particular model. The scale of intensities for each objective appears as a group of nodes under that objective. The intensities are prioritized through the usual pairwise comparison process. Alternatives do not appear within the main structure of the tree, but instead are maintained in the Ratings spreadsheet. Each alternative is then rated against the established scale of intensities defined for each criterion. The scores for each alternative are weighted according to the priorities derived from the pairwise comparison process and then summed to determine the overall score. When alternatives are rated in this way, the alternatives are not compared against each other, but against the standard scales that have been derived for each criterion.

Model Structure

Figure A-2 below depicts the tree structure for the preliminary model. The goal as shown on the top of the screen is to "Select the best alternatives for mercury retirement".

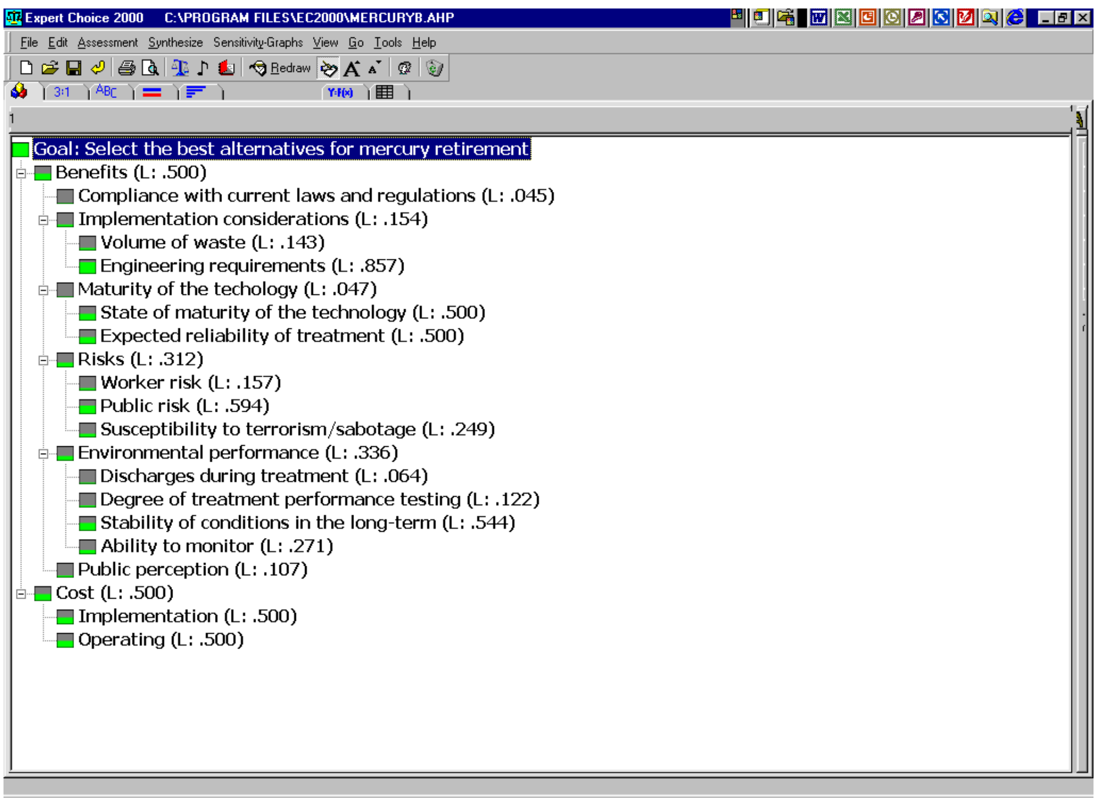


Figure A-2 Decision Model Tree Structure

The top level criteria are Benefits and Cost. The associated objectives obviously are to maximize the benefits and to minimize the costs. Equal weightings were assigned to each of these top level objectives. Each of these objectives include one level or more sub-objectives as seen in Figure A-2. Six sub-objectives were defined for the covering Benefits objective, four of which was further broken down into additional sub-objectives. Two objectives were defined for the covering Cost objective. These are detailed below:

Benefits

- Compliance with current laws and regulations (maximize)
- Implementation considerations
    - Volume of waste (minimize)
    - Engineering requirements (minimize)
- Maturity of the technology
    - State of the maturity of the technology (maximize)
    - Expected reliability of treatment (maximize)
- Risks (minimize)
    - Risks to worker (minimize)
    - Risks to public (minimize)
    - Susceptibility to terrorist attack or sabotage (minimize)
- Environmental performance
    - Discharges during treatment (minimize)
    - Degree of treatment performance testing (maximize)
    - Stability of conditions in the long term (maximize)
    - Ability to monitor (maximize)
- Public perception (maximize positive reaction)

Cost

- Implementation costs (minimize)
- Operating costs (minimize)

The derived priorities for the Benefits sub-objectives from the pairwise comparison by the team's scientists can be seen in Figure A-3. Equal priorities were given to the two Cost sub-objectives.

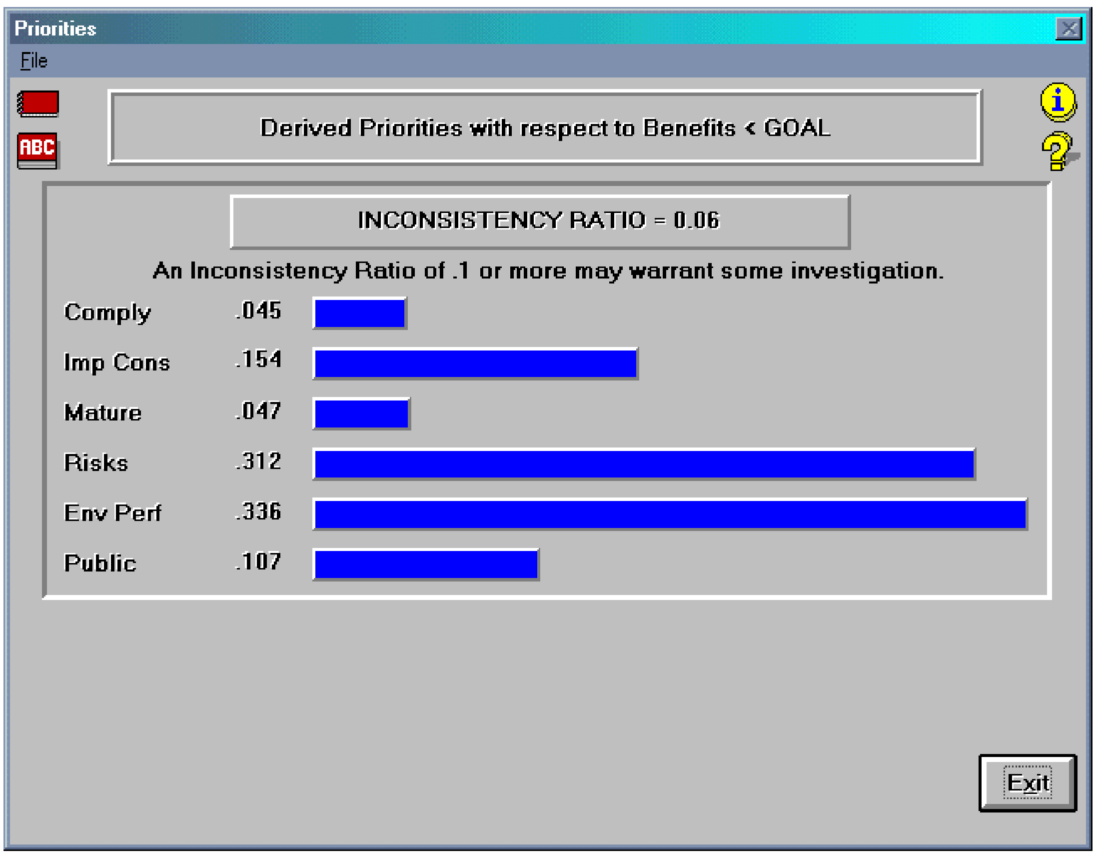


Figure A-3 Derived Benefits Sub-objectives Priorities

The resulting priorities shown are normalized and indicate that the environmental performance and the potential for catastrophic accidents are the most significant criteria when evaluating options for retirement of mercury.

The rating intensity scales defined for each objective/criterion are shown in Table A-1.

Table A-1. Rating Intensities Scale

Covering Objective	Criteria	Rating Scale Parameters
Cost	Implementation cost	Low (0.717)[a] Medium (0.205) High (0.078)
	Operating cost	Low (0.717) Medium (0.205) High (0.078)
Benefits	Compliance with current laws and regulations	Compliant (0.731) Non-complaint with LDRs (0.188) Atypical permit required (0.081)
	Public perception	Positive to neutral (0.833) Negative (0.167)
Benefits: Implementation Considerations	Volume of waste	Zero or minimal (0.731) Increase up to 10 times (0.188) Increase greater than 10 times (0.081)
	Engineering requirements	Existing or minor modifications (0.731) New facilities (0.188) Construction of a mined cavity (0.081)
Benefits: Maturity of the technology	State of the maturity of the technology	Full-scale operation (0.731) Pilot treatment/full-scale disposal (0.188) Pilot treatment/untested disposal (0.081)
	Expected reliability of treatment	No treatment (0.717) Simple (0.205) Complex (0.078)
Benefits: Risk	Worker risk	Very Low (0.800) Low (0.200)
	Public risk	Very Low (0.800) Low (0.200)
	Susceptibility to terrorist attack or sabotage	Very Low (0.800) Low (0.200)
Benefits: Environmental Performance	Discharges during treatment	No impact (0.833) Minimal (0.167)
	Degree of treatment performance testing	Adequate (0.705) Moderate (0.211) Low (0.084)
	Stability of conditions in the long term	Very good (0.554) Good (0.289) Fair (0.106) Poor (0.051)
	Ability to monitor	Easy and correctable (0.649) Easy (0.279) Difficult (0.072)

[a] The figures in parentheses are the relative weights given to each intensity.

The corresponding weights determined from comparison of the intensities are shown in Figures A-4 through A-27.

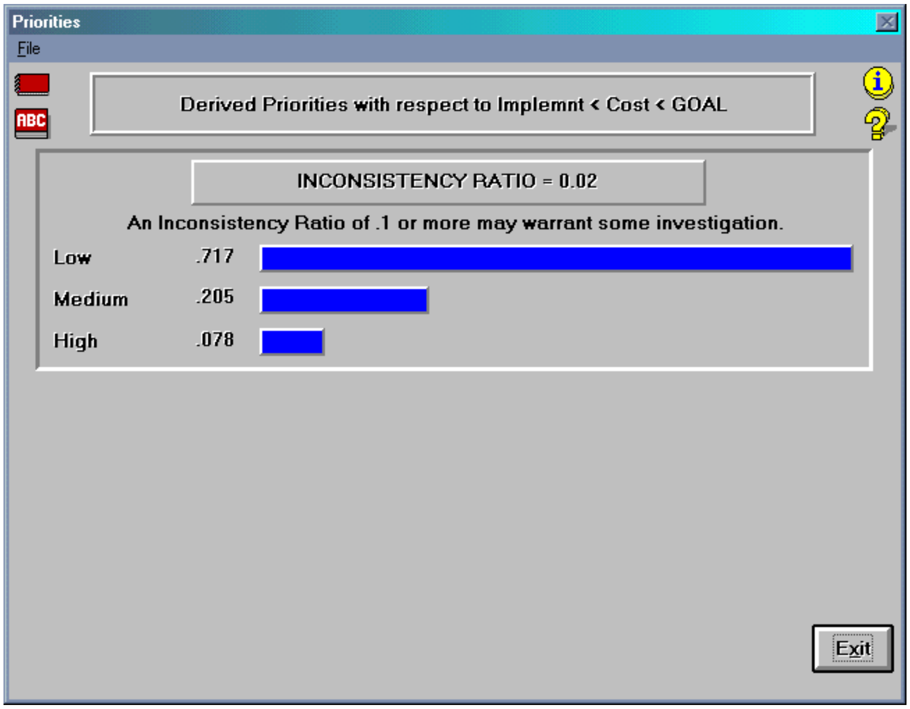


Figure A-4 Derived Priorities for Implementation Costs and Operating Costs with Respect to Cost

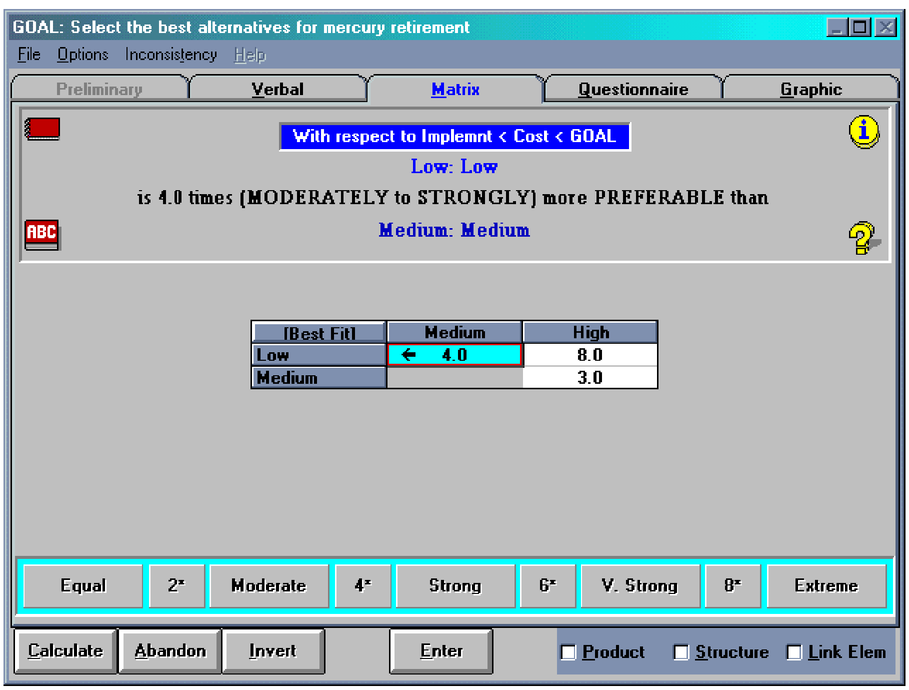


Figure A-5 Pairwise Judgements of Implementation Cost Rating Scale Parameters

The pairwise judgements for the Operating cost rating scale parameters were identical to that of the implementation costs.

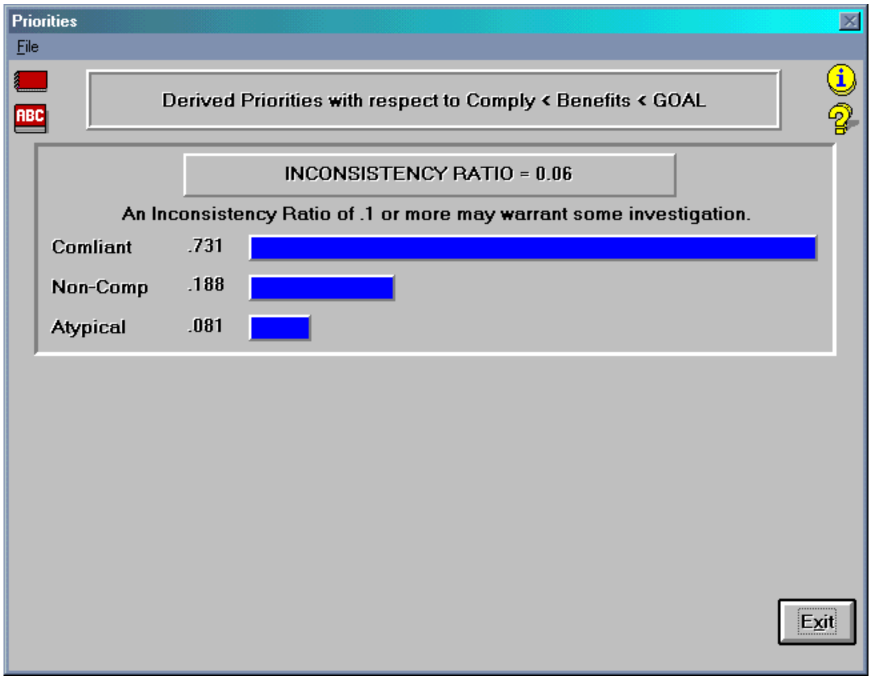


Figure A-6 Derived Priorities for Compliance with Current Laws and Regulations with Respect to Benefits

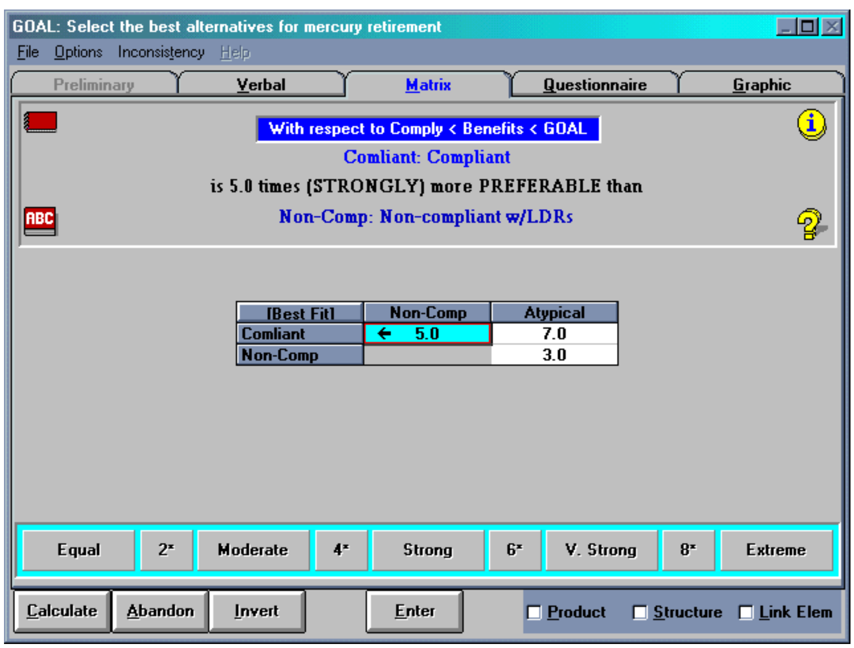


Figure A-7 Pairwise Judgements of Compliance with Current Laws and Regulations Rating Scale Parameters

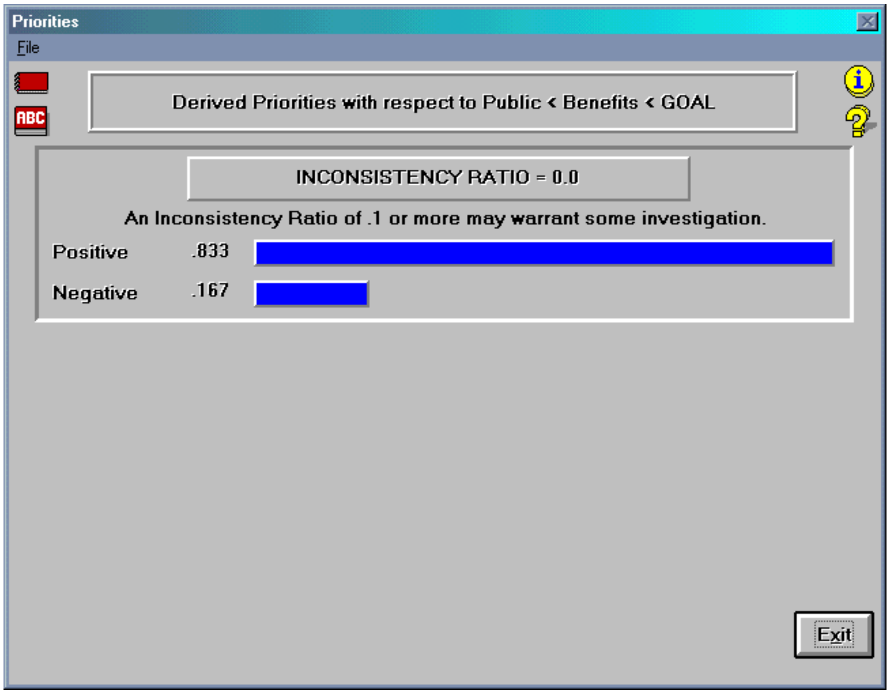


Figure A-8 Derived Priorities for Public Perception with Respect to Benefits

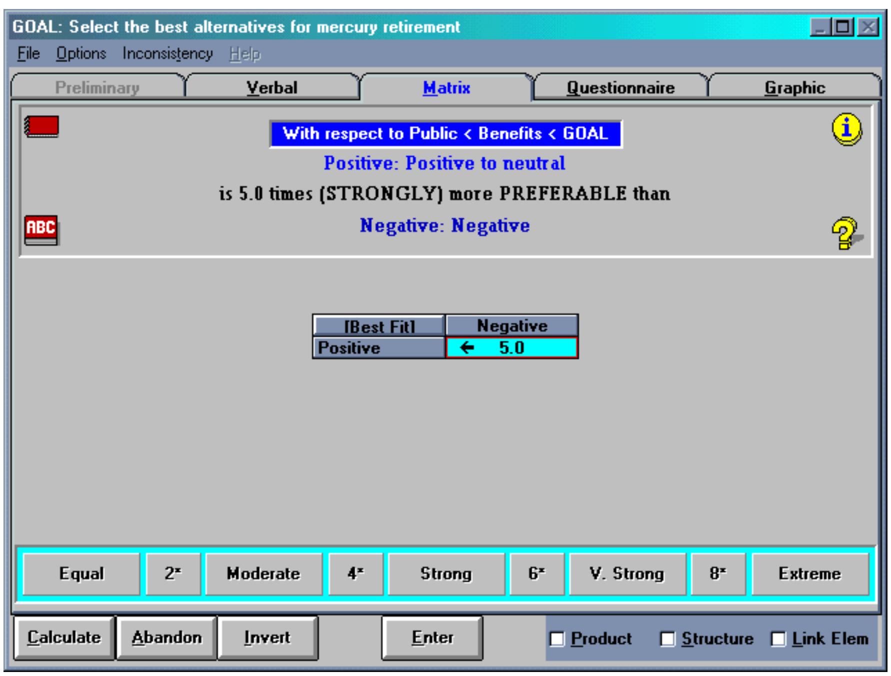


Figure A-9 Pairwise Judgements of Public Perception Rating Scale Parameters

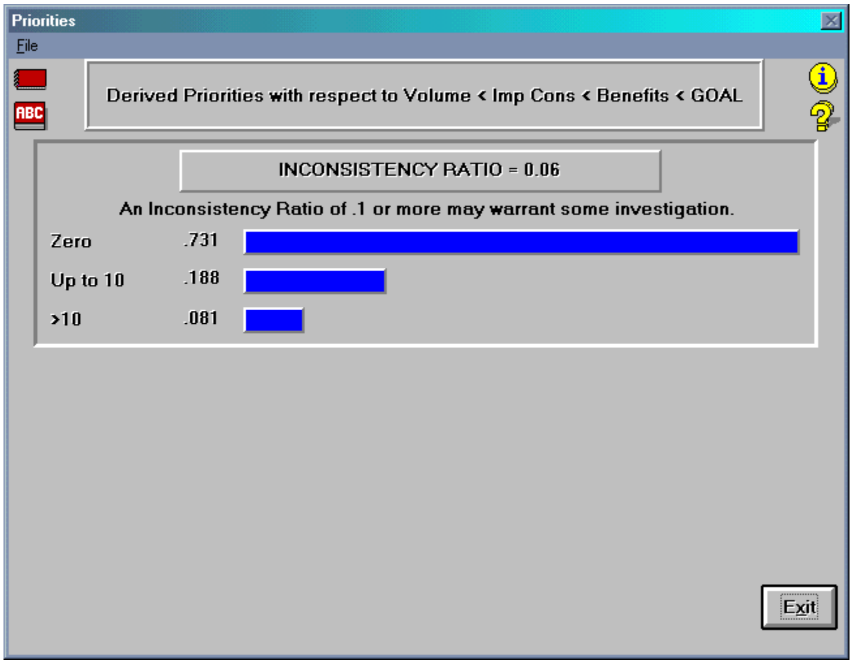


Figure A-10 Derived Priorities for Volume of Waste with Respect to Implementation Considerations

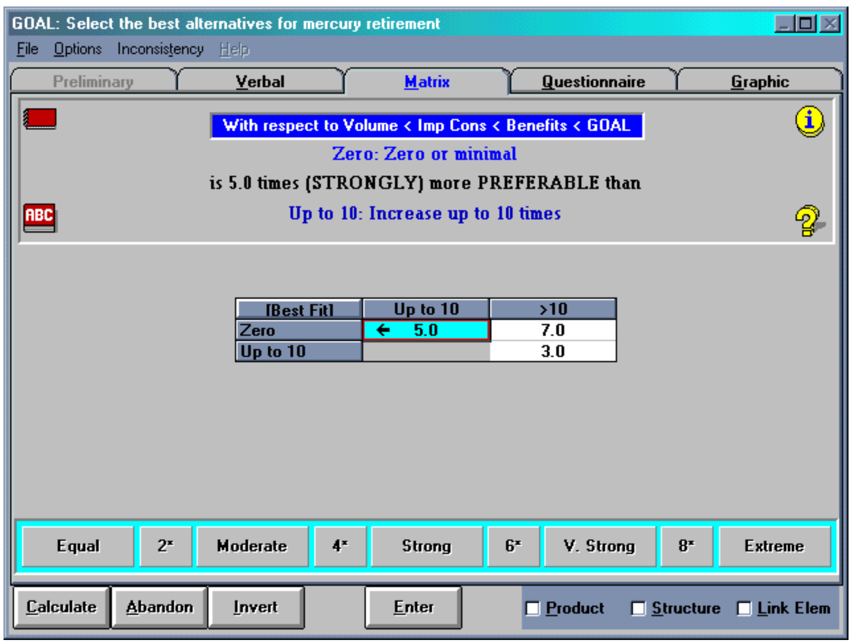


Figure A-11 Pairwise Judgements of Volume of Waste Rating Scale Parameters

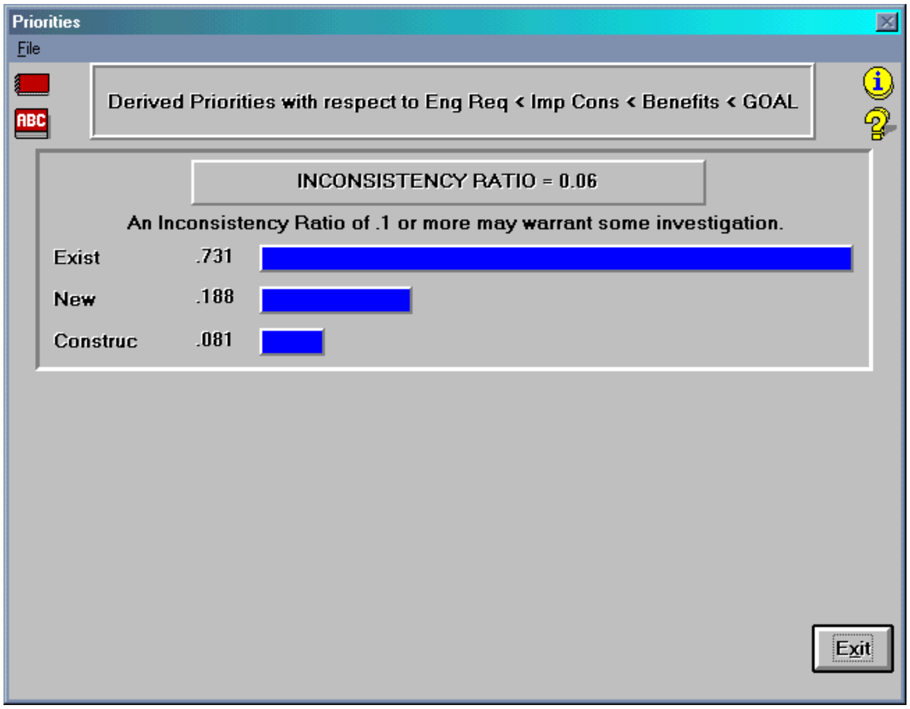


Figure A-12 Derived Priorities for Engineering Requirements with Respect to Implementation Considerations

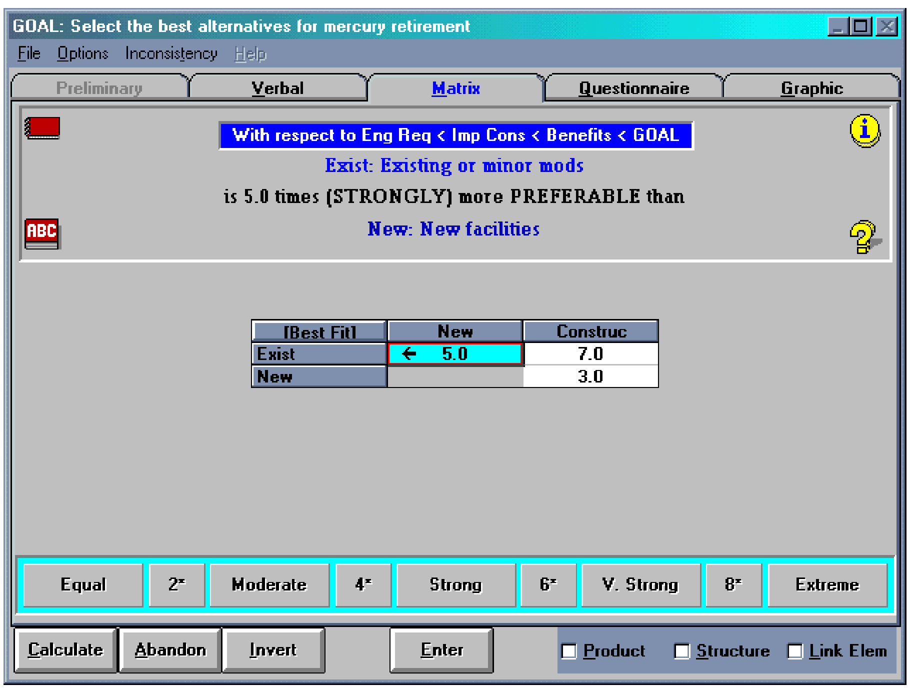


Figure A-13 Pairwise Judgements of Engineering Requirements Rating Scale Parameters

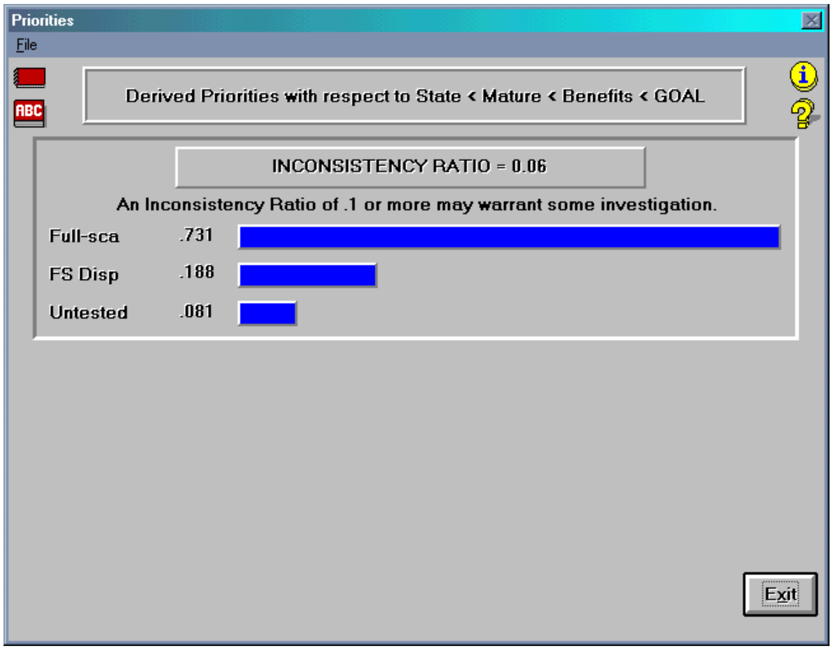


Figure A-14 Derived Priorities for State of Maturity of the Technology with Respect to Maturity of the Technology

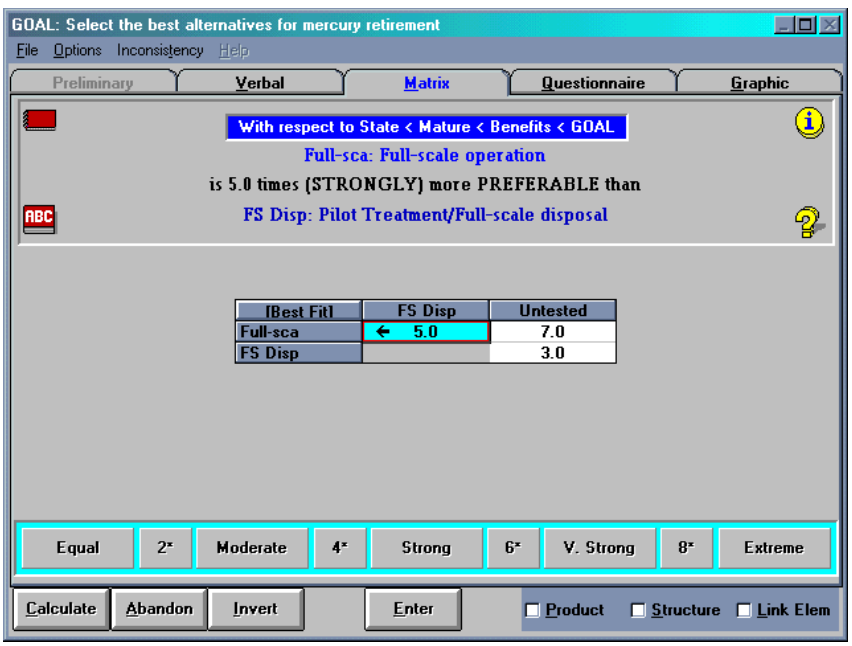


Figure A-15 Pairwise Judgements of State of Maturity of the Technology Rating Scale Parameters

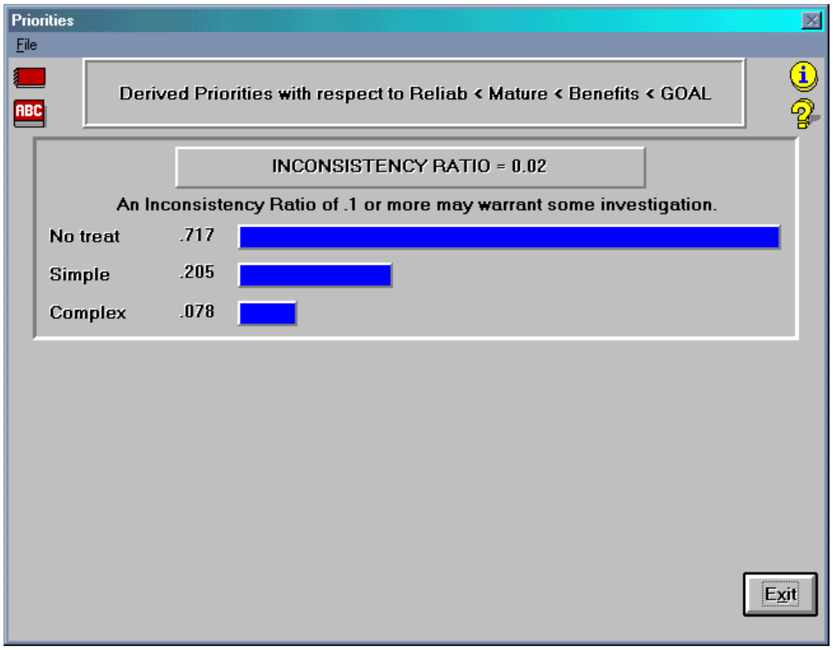


Figure A-16 Derived Priorities for Expected Reliability of Treatment with Respect to Maturity of the Technology

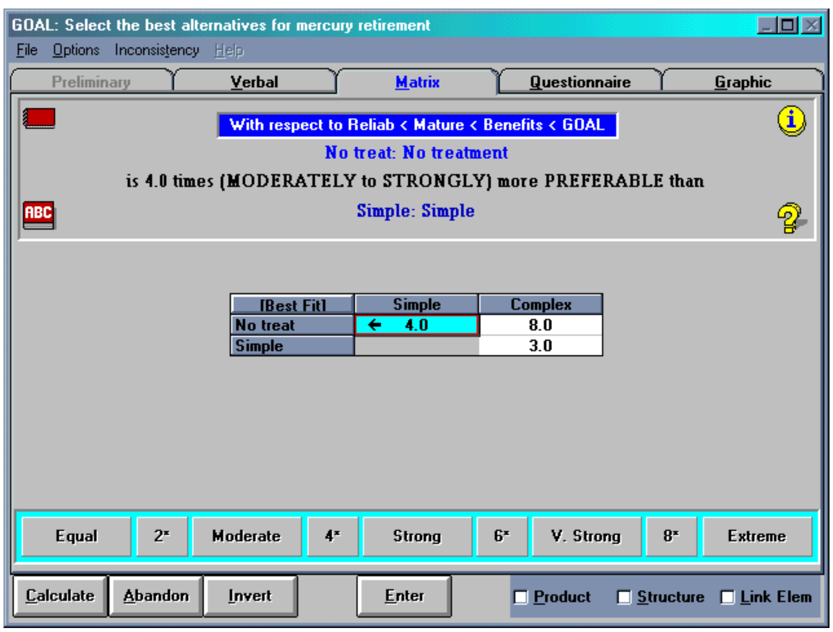


Figure A-17 Pairwise Judgements of Expected Reliability of Treatment Rating Scale Parameters

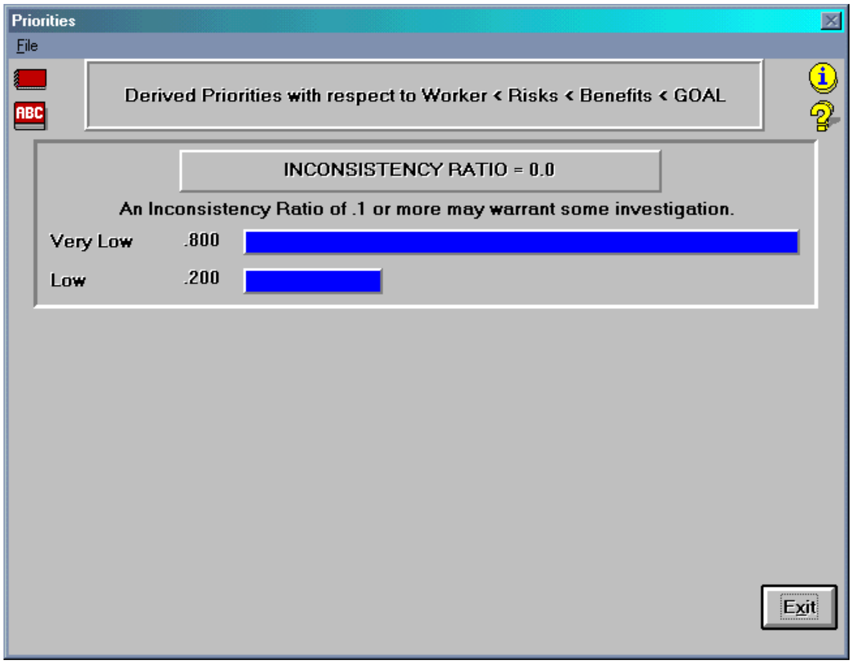


Figure A-18 Derived Priorities for Worker Risk with Respect to Risks

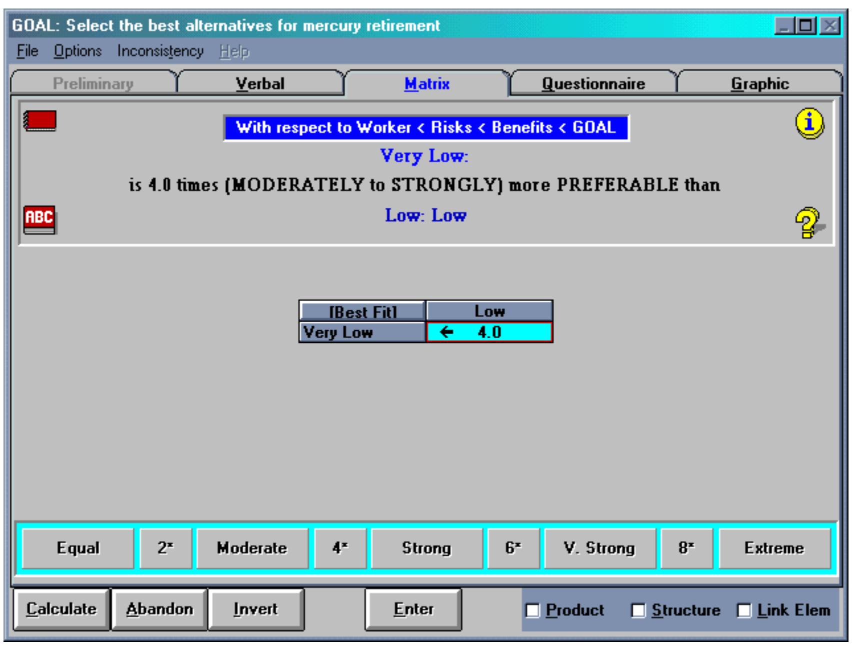


Figure A-19 Pairwise Judgements of Worker Risk Rating Scale Parameters

The derived priorities and pairwise judgements for the public risk and susceptibility to terrorist attack or sabotage criteria were identical to that of the worker risk shown in the above two figures.

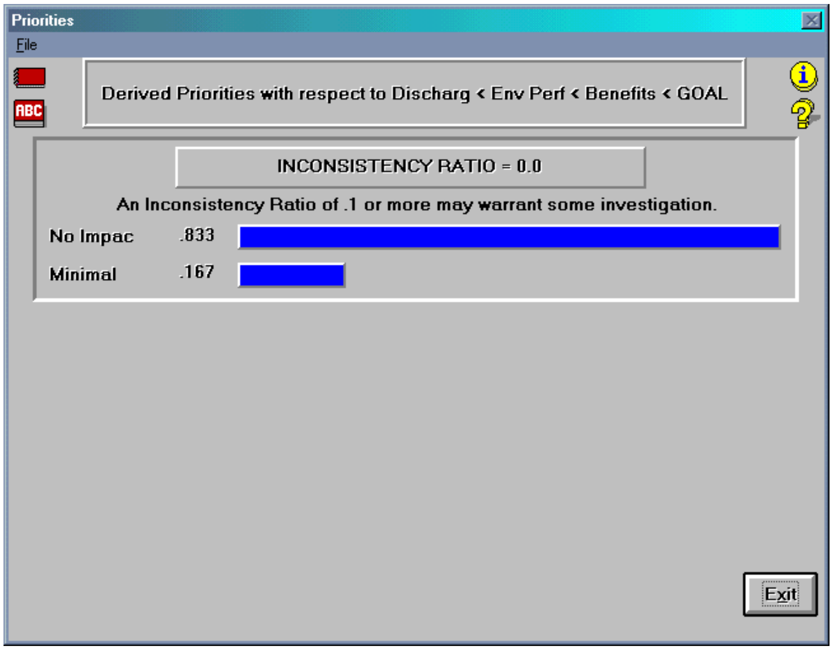


Figure A-20 Derived Priorities for Discharges During Treatment with Respect to Environmental Performance

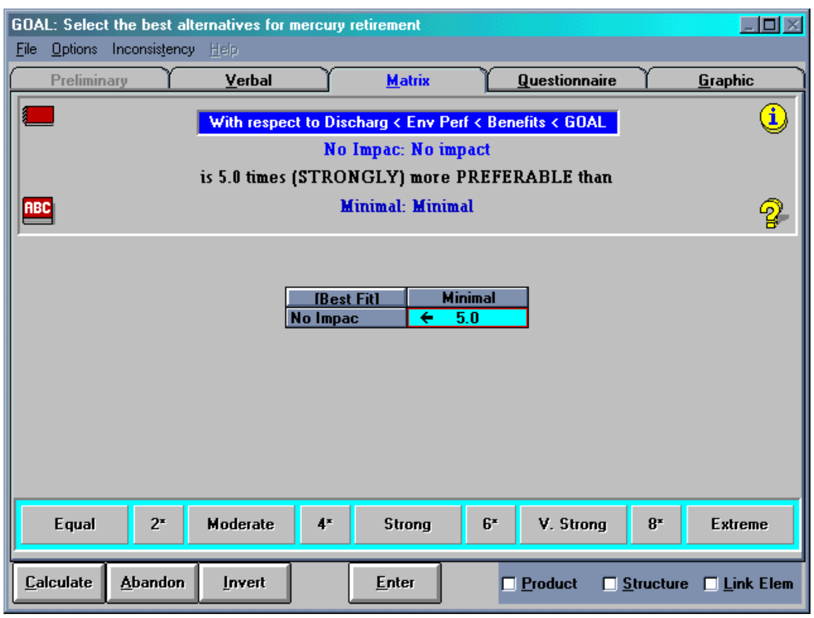


Figure A-21 Pairwise Judgements of Discharges During Treatment Rating Scale Parameters

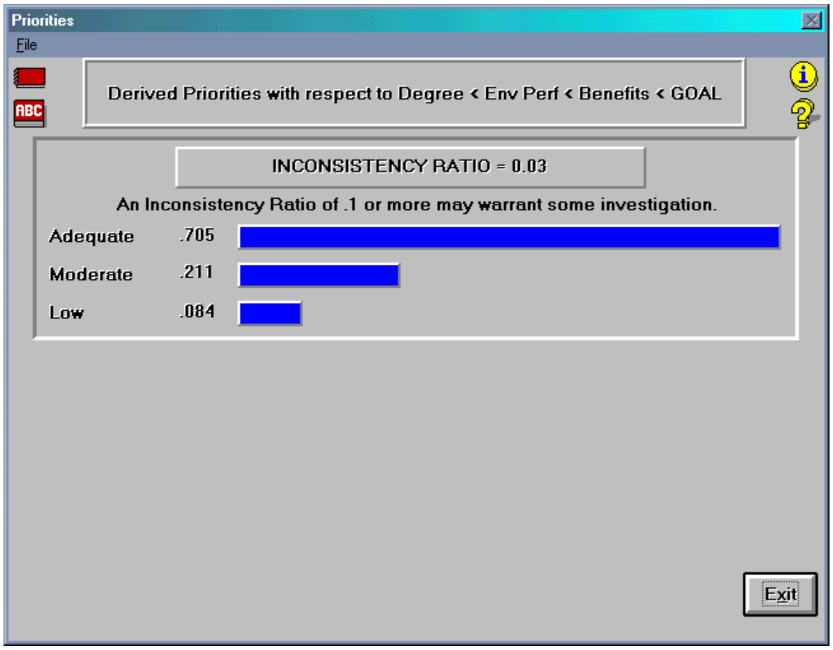


Figure A-22 Derived Priorities for Degree of Treatment Performance Testing to Environmental Performance

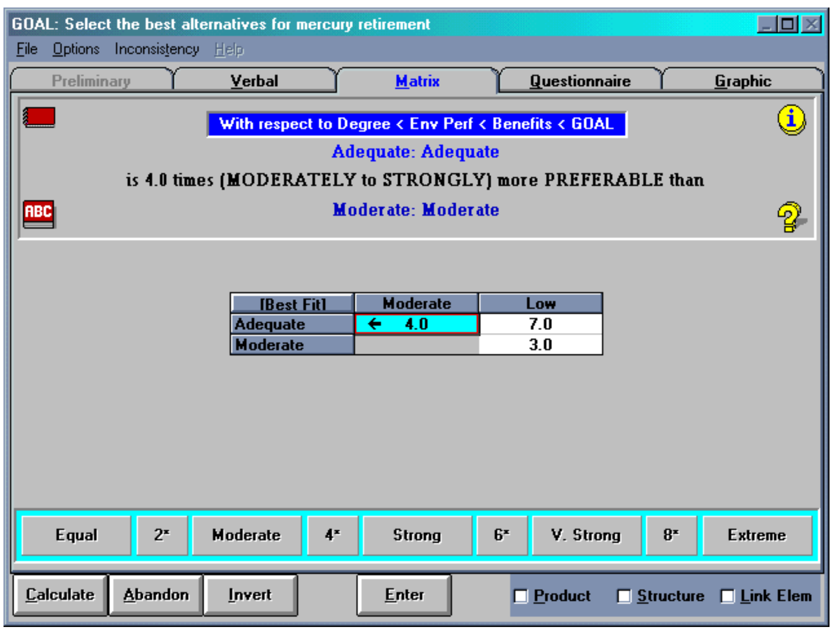


Figure A-23 Pairwise Judgements of Degree of Treatment Performance Testing Rating Scale Parameters

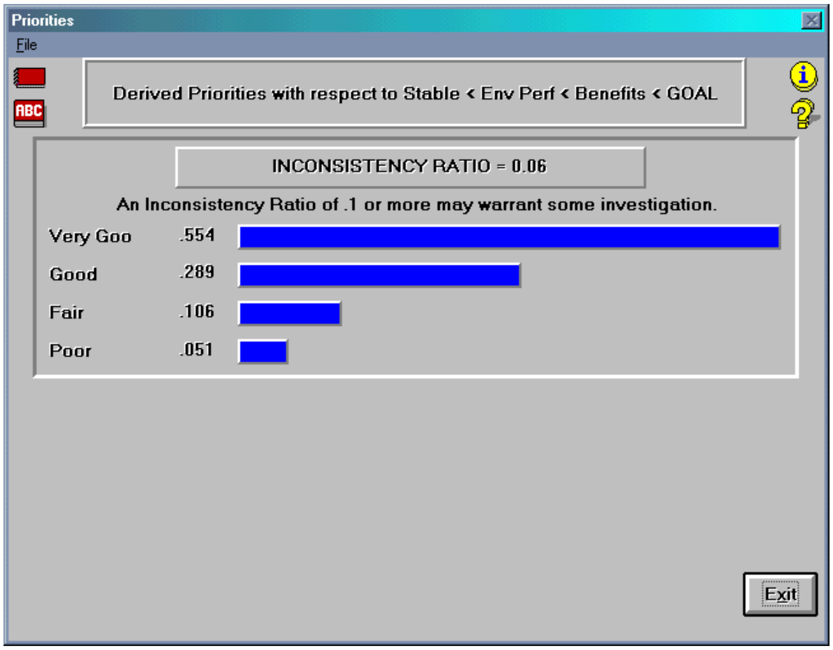


Figure A-24 Derived Priorities for Stability of Conditions in the Long Term to Environmental Performance

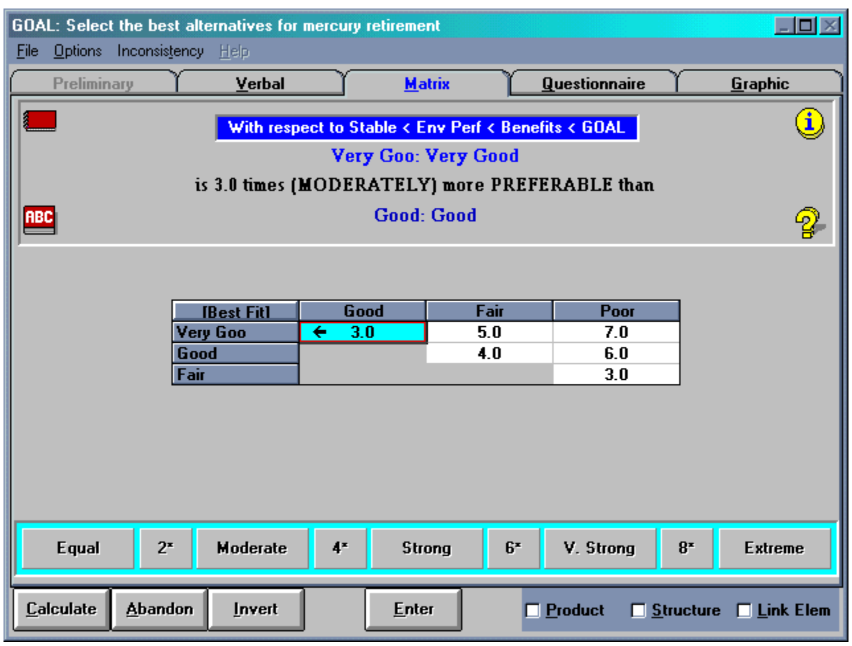


Figure A-25 Pairwise Judgements of Stability of Conditions in the Long Term Rating Scale Parameters

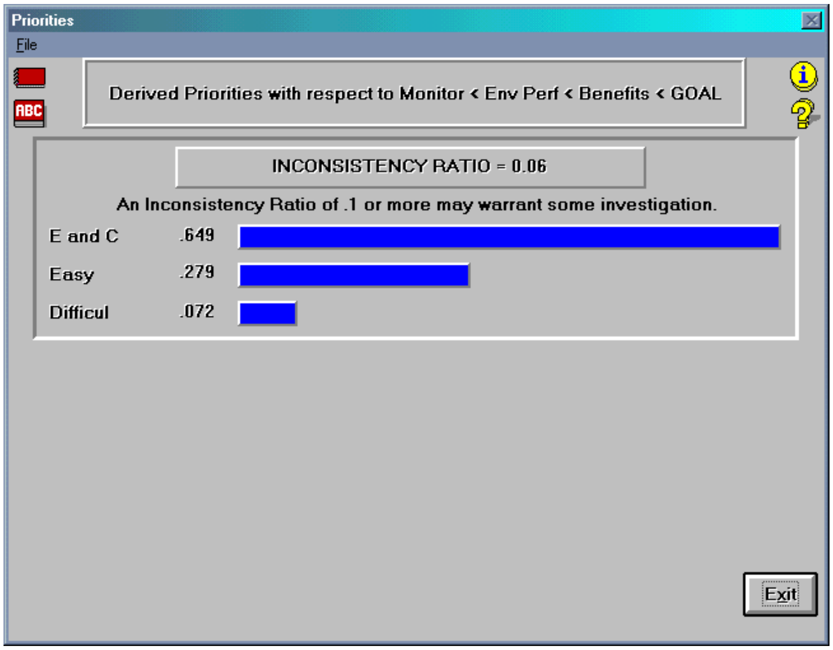


Figure A-26 Derived Priorities for Ability to Monitor to Environmental Performance

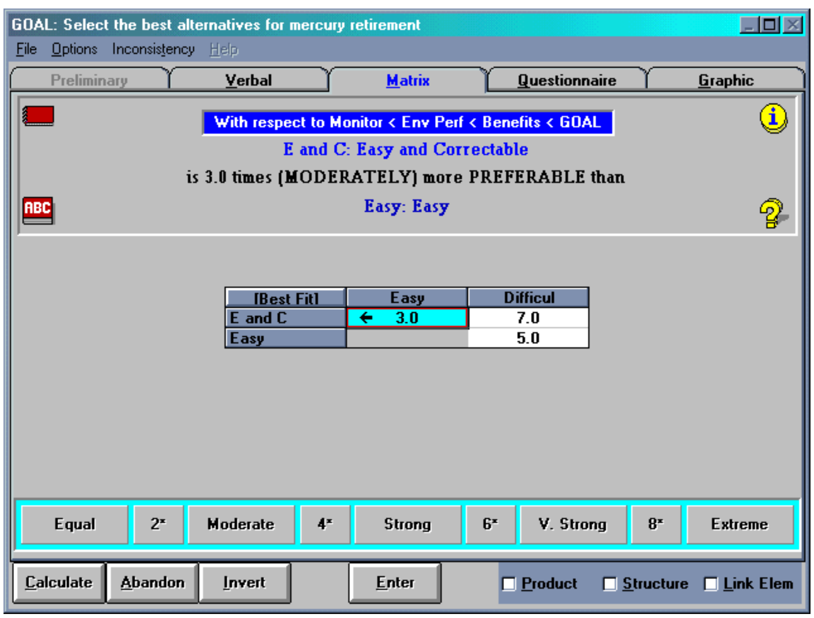
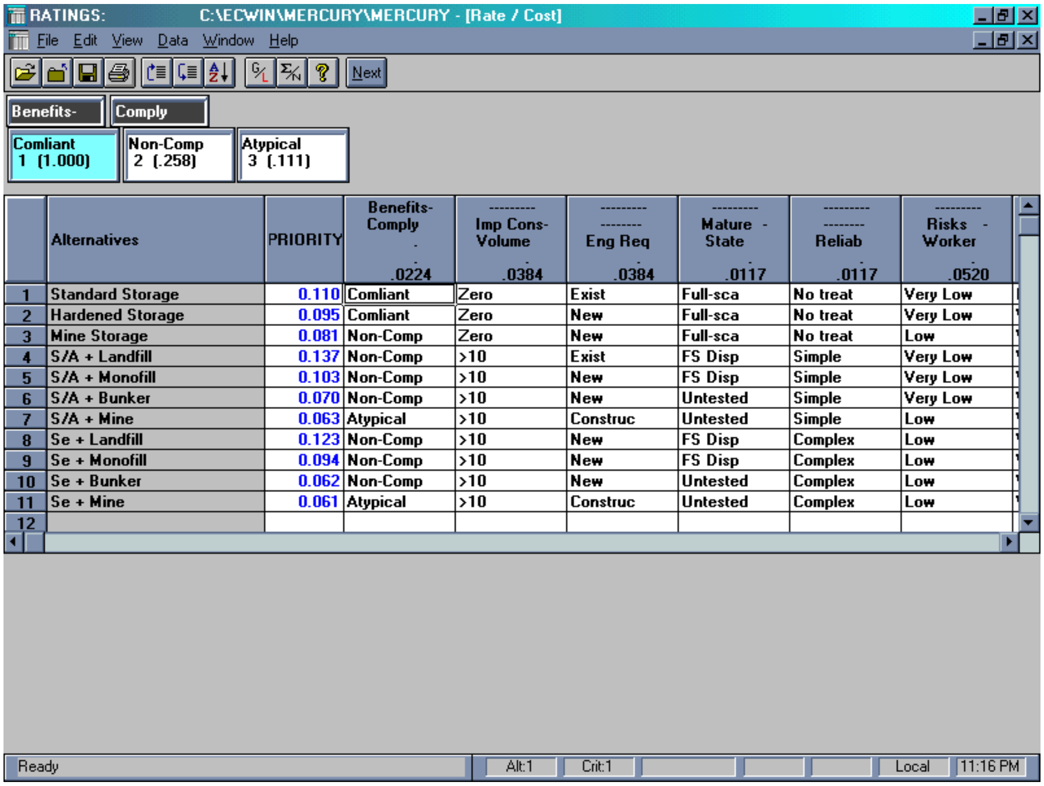


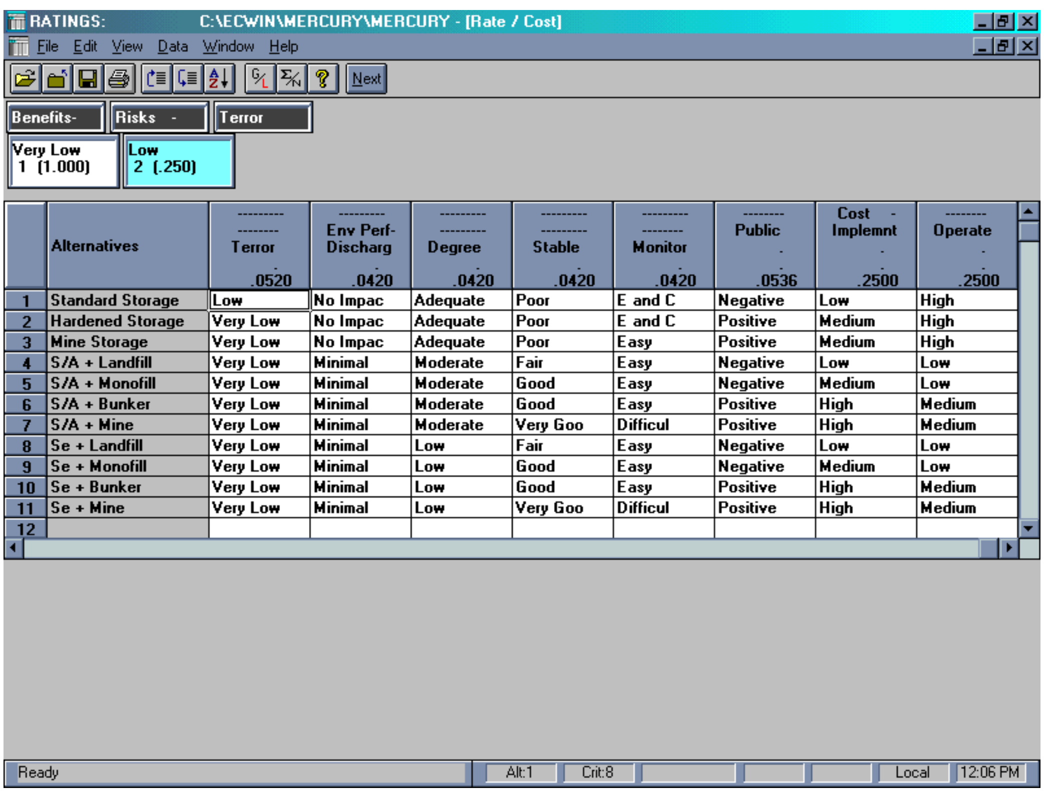
Figure A-27 Pairwise Judgements of Ability to Monitor Rating Scale Parameters

The derived priorities of the objectives with respect to the goal and of the rating intensities with respect to the sub-objectives or criteria were then fed into the ratings worksheet. A rating for each criterion for each alternative is then made. Figures A-28 and A-29 below display the completed ratings worksheet.



	Alternatives	PRIORITY	Benefits- Comply .0224	Imp Cons- Volume .0384	Eng Req .0384	Mature - State .0117	Reliab .0117	Risks - Worker .0520
1	Standard Storage	0.110	Comliant	Zero	Exist	Full-sca	No treat	Very Low
2	Hardened Storage	0.095	Comliant	Zero	New	Full-sca	No treat	Very Low
3	Mine Storage	0.081	Non-Comp	Zero	New	Full-sca	No treat	Low
4	S/A + Landfill	0.137	Non-Comp	>10	Exist	FS Disp	Simple	Very Low
5	S/A + Monofill	0.103	Non-Comp	>10	New	FS Disp	Simple	Very Low
6	S/A + Bunker	0.070	Non-Comp	>10	New	Untested	Simple	Very Low
7	S/A + Mine	0.063	Atypical	>10	Construc	Untested	Simple	Low
8	Se + Landfill	0.123	Non-Comp	>10	New	FS Disp	Complex	Low
9	Se + Monofill	0.094	Non-Comp	>10	New	FS Disp	Complex	Low
10	Se + Bunker	0.062	Non-Comp	>10	New	Untested	Complex	Low
11	Se + Mine	0.061	Atypical	>10	Construc	Untested	Complex	Low
12								

Figure A-28 Completed Ratings Worksheet (First Page)



	Alternatives	Terror .0520	Env Perf- Discharg .0420	Degree .0420	Stable .0420	Monitor .0420	Public .0536	Cost - Implemnt .2500	Operate .2500
1	Standard Storage	Low	No Impac	Adequate	Poor	E and C	Negative	Low	High
2	Hardened Storage	Very Low	No Impac	Adequate	Poor	E and C	Positive	Medium	High
3	Mine Storage	Very Low	No Impac	Adequate	Poor	Easy	Positive	Medium	High
4	S/A + Landfill	Very Low	Minimal	Moderate	Fair	Easy	Negative	Low	Low
5	S/A + Monofill	Very Low	Minimal	Moderate	Good	Easy	Negative	Medium	Low
6	S/A + Bunker	Very Low	Minimal	Moderate	Good	Easy	Positive	High	Medium
7	S/A + Mine	Very Low	Minimal	Moderate	Very Goo	Difficul	Positive	High	Medium
8	Se + Landfill	Very Low	Minimal	Low	Fair	Easy	Negative	Low	Low
9	Se + Monofill	Very Low	Minimal	Low	Good	Easy	Negative	Medium	Low
10	Se + Bunker	Very Low	Minimal	Low	Good	Easy	Positive	High	Medium
11	Se + Mine	Very Low	Minimal	Low	Very Goo	Difficul	Positive	High	Medium
12									

Figure A-29 Completed Ratings Worksheet (Second Page)

The overall totals can be seen on the first page of the ratings worksheet which provides the priority of alternatives. The top nine alternatives were then extracted back to the pairwise comparison model so that sensitivity analysis on the objectives and criteria could be conducted to see how well the alternatives performed with respect to each of the objectives as well as how sensitive the alternatives are to changes in the importance of the objectives.

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Saaty, Thomas L. 1980. *The Analytic Hierarchy Process.* New York: McGraw-Hill.

The Analytic Sciences Corporation (TASC). Undated. *An Illustrated Guide to the Analytic Hierarchy Process*.