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A Multi Attribute Trade Off and Analysis Framework for Electric Utility Integrated Resource Planning

by

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Multi Attribute Planning for Electric Utilities

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A Multi Attribute Trade Off and Analysis Framework for Electric Utility Planning

Section 1: Introduction

The Integrated Resource Planning (IRP) framework described in Trade-Off Analysis for Electric Power Planning in New England: A Methodology for Dealing with Uncertain Futures (referred to henceforth as Volume 1 of the Energy Laboratory's series of papers on Multi Attribute Planning for Electric Utilities) consists of two primary components: scenario analysis and multi attribute trade off analysis. The scenario development and analysis is proposed to explicitly consider the massive uncertainties associated with the future demand and supply of electricity. The trade off analysis, as the name suggests, allows the Advisory Group participant to explore the trade offs for a range of attributes and uncertainties inherent in choosing one strategy over another.

This paper (Volume 2 of the series) concentrates on addressing the lack of tools available to effectively perform trade off analysis for a large data base. A Multi Attribute Trade Off Framework (MATOF) and a set of tools are developed and presented. Because of the large amount of data and the three-dimensional nature of the simulation results (an outcome of considering not only attributes and strategies but also uncertainties), it is extremely difficult for participants to efficiently and fully explore the implications of the available choices.[1] Therefore, the primary components of the framework are

[1]Research into the cognitive processes of decision makers [Payne, 1976; Olshavsky, 1979] indicates that, even with certainty about the outcomes, people are not able to fully consider the majority of the information available about an alternative until they have reduced the number of alternatives and

aimed at facilitating the analysis. The close interaction between the trade off analysis and the initial structuring of objectives, strategies, attributes, and uncertainties should not be overlooked, however. This relationship is treated in the a priori information elicitation stage.

The trade off analysis framework must satisfy a number of requirements in order to achieve the goals of the Integrated Resource Planning process. In short, they are:

1. The ability to handle thousands of attribute vectors
2. Conceptually easy to understand and use
3. Comparisons across strategies for a particular future
4. Comparisons of the same strategy across different futures
5. Identify dominated strategies
6. Elimination of irrelevant uncertainties
7. Fully utilize probabilities for uncertainties and futures, if available

The framework presented in this chapter is a combination of a set of tools that address the analysis requirements and a recommended structure that guides the participant through the steps necessary to gain a full understanding of the implications of a particular choice. It should be noted, however, that the components of the framework stand on their own. This allows the participant to approach the data in a different manner, if they wish to focus on a particular issue or problem[1]. In addition, some of the stages of MATOF

attributes to a small number (the more attributes considered, the fewer the number of alternatives "efficiently" processed).

[1] This is not recommended until the participant has had the opportunity to utilize the entire framework at least once. MATOF has been structured to direct the participant through the entire set of issues and trade offs; a more random application of the tools could be misleading.

include a variety of tools and measures. In some cases, all of the suggested methods must be utilized in order to obtain the intended result. In others, however, a subset is sufficient.

A number of definitions must be reviewed/introduced before pursuing the discussion of the framework:

Options: Choices available to decision-makers. These include demand-side management (DSM) programs, purchases from neighboring utilities or independent power producers, construction of gas, oil or coal-fired facilities, etc.

Strategy: a particular set or combination of options.

Uncertainties: Events that cannot be controlled. Examples include fuel prices, participation rates in DSM programs, and capital costs.

Future: a particular set or combination of uncertainties.

Scenario: a set of options combined with a set of uncertainties (i.e. a strategy combined with a future

Attributes are measures of performance or "goodness" of alternatives. Examples include cost of electricity, number or duration of blackouts, etc.

Objectives indicate the desires of the decision makers and the direction in which they want to move. The objectives of the government in designing a plan for national defense might be to minimize cost, maximize troop numbers, and maximize the ability to respond to crisis situations, etc.

Goals are specific target levels of attributes, i.e. achieve a cost of 7¢/kWh. Because they can restrict the range of possible action, goals are often called constraints. These are not objectives as we have defined them above.

Strategy set is the set **X** which consists of all possible strategies, x_p.

Attribute vector (also known as the image of x_{pf}) is the set of values that the attributes take on for a specific scenario. Written as $\mathbf{a}_{pf} = (a_1, \ldots\ldots, a_n)$, where the a_i could be vectors, scalars, qualitative or quantitative data.

x_{p1f} is said to dominate x_{p2f} if $f_i(x_{p1f}) \leq f_i(x_{p2f})$ for all i, with strict inequality for at least one i (this assumes that all of the objective functions are to be minimized). In other words, a strategy for which it is not possible to find a competitor that performs better on every attribute belongs to the set of non-dominated strategies, also known as the efficient set. A local efficient set is the set of non-dominated alternatives for a particular future. The global efficient set is the union of all local efficient sets.

x_{p1f} is said to significantly dominate x_{p2f} if it is significantly better (tolerance ranges must be determined by the decision maker) for a subset of the attributes, and only marginally worse for the remaining attributes.

Feasible strategies are those members of the strategies set **X** which satisfy any constraints on the problem.

The decision matrix ,$\mathbf{D}_f$, is the matrix formed by stacking the attribute vectors $\mathbf{a}_{pf}$ on top of each other for all the strategies in a particular future f. **D** is the matrix formed by stacking all $\mathbf{D}_f$, for all possible futures. This is simply the tabular form of the results.

The remainder of this chapter is organized as follows. Section 2 introduces the proposed framework. A brief introduction to the electric utility planning study (discussed in more detail in Volume 1) is presented in Section 3. The results of this study will be used to provide examples in the ensuing presentation and discussion. The components of MATOF are discussed in detail in Sections 4-10. A brief concluding section completes the paper.

Section 2 A Multi Attribute Trade Off and Analysis Framework

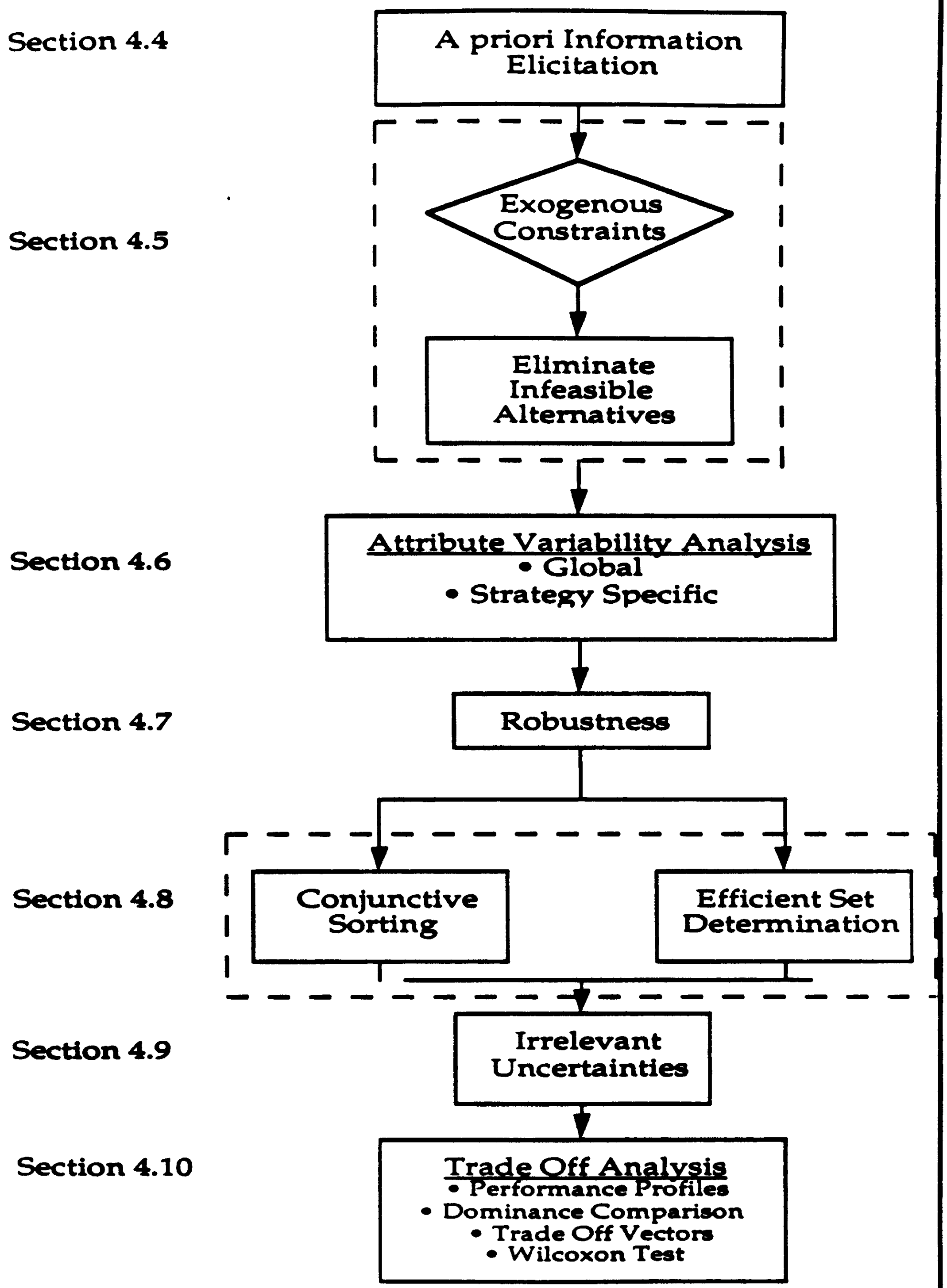
Figure 1 is a flowchart diagramming the components of the proposed trade off analysis structure, a listing of some of the tools, and the suggested order of implementation. There are seven distinct components in the framework: 1) A priori information elicitation, 2) exogenous constraints, 3) attribute variability analysis, 4) robustness, 5) sorting and efficient sets, 6) irrelevant uncertainties, and 7) trade off analysis.

This framework is intended for use by participants' in an Advisory Group as a structured algorithm for exploring the results of the scenario simulations. Although all of the stages can stand alone or be utilized in a different manner than that presented in Figure 1, the proposed configuration will guide the decision maker through a complete, yet flexible, analysis. It has also been designed so that a new Advisory Group member unfamiliar with the IRP process could utilize the data from an earlier study to the learn the concepts and premises behind the methodology.

The two most important stages open and close the analysis. The A priori information elicitation stage connects the trade off analysis to the discussions in the Advisory Group and shapes the individual's analysis in the trade off structure so that it is relevant and useful to the Advisory Group's function in the IRP process.

Figure 1

A Multi Attribute Trade Off Framework



The trade off analysis, and the set of tools introduced in Section 10, is at the core of the proposed framework. In this stage the participants have the opportunity to explore the trade offs that are implied by the options and strategies. After the completion of this assessment, the participant can return to the Advisory Group and discuss his/her favorite strategies with quantitative information about the impacts that this strategy will have on other members and with an understanding of the effects that other strategies will have on the attributes that he/she feel are particularly important.

The remaining five stages act as a funnel, taking the large data set from the scenario analysis and helping to focus attention on certain characteristics of the attributes, strategies and uncertainties. The trade off analysis stage operates most effectively when the participant "knows where to look", particularly when a large number of attributes and strategies exist; these stages are aimed at suggesting comparisons that are worthy of the participant's attention. The results from the information elicitation stage play an important role in this process, acting as a regulator or conductor of the flow of information and directing the next stages.

Of course the participant is welcome to explore the data and use the tools in the framework without following the structure. Personal experience suggests, however, that this is at best a very confusing and difficult way to draw conclusions about the results and can direct the participant to misleading or incorrect results.

Given a correctly specified and formatted decision matrix, MATOF flows as follows:

• In the a priori information stage (Section 4), the participant is first familiarized with the IRP approach, if necessary. More importantly, the questions posed in this stage are designed to help the decision maker explore a priori their preferences and knowledge, in order to structure their own analysis and to help the other participants consider trade offs across the group.

• In the next stage, exogenous constraints (Section 5), strategies that exceed some exogenously defined allowable attribute values are eliminated. Federal emission constraints are a possible example.

• The attribute variability stage (Section 6) includes several different measures to help the participants familiarize themselves with the data. This is important because the variation across the attributes will help to define how the decision maker evaluates the trade offs.

• The identification and potential elimination of non-robust alternatives (Section 7) can be used to prune out the unacceptably variable strategies (which can mask more "robust" plans) in the cases where efficient sets are being used to eliminate strategies. This ensures that the participant is focusing their attention on a set of strategies that are all "acceptably" robust. The data analysis, and the insights it provides into the range of attribute outcomes, plays an important role in helping the participant in identifying the non-robust alternatives.

• Sorting and the selection of efficient sets (Section 8) indicates which strategies appear to be either particularly good or bad. This helps the participant to select strategies that, combined with those defined a priori to be of special interest, should form a small enough subset to allow the trade offs to be examined in detail.

• The identification of irrelevant uncertainties (Section 9) depends critically on the definition of the term "irrelevant". A method is suggested in this stage which focuses on the relative position of the strategies in attribute space as an uncertainty is varied. The identification of these uncertainties can help to structure and focus the discussion in the Advisory Group and to reduce the analysis required in the trade off stage.

• The trade off analysis (Section 10) is at the core of MATOF and addresses the most significant failure of other multi attribute decision making techniques - MATOF allows the participant to explore the trade offs <u>available</u> in the set of strategies and attributes under study, rather than seeking to understand the decision maker's <u>preferred</u> trade offs. The tools are all simple to use (assuming the development of appropriate software) and understand. The previous stages have helped to identify strategies and even certain trade offs that are critical. The trade off stage should focus on these first. This is not to suggest that time, if available, should not be spent trying to interpret and understand the trade offs implied by all the possible combinations of choices. However, research on cognitive abilities and my own experience suggest that participants are only able to focus effectively on a small subset of choices and still fully appreciate the associated attributes values.

Volume 1 identifies 4 stages in the IRP process: issues/attribute identification, scenario development, scenario simulation, and trade off analysis[1]. With the exception of the a priori information elicitation stage, all of the remaining six stages are designed to be used in the trade off analysis portion of the IRP process[2]. The a priori information stage is appropriately applied to the issues/attribute identification, scenario development and trade off analysis steps.

Section 3 Example Description

This section presents a brief overview of an IRP-based study performed by the Analysis Group for Regional Energy Alternatives (AGREA) of the Energy Laboratory at MIT in 1988. The results of this study, which focused on a limited number of the options available to New England's planners, will be used to demonstrate in detail how the seven steps of the trade off framework presented in this chapter would be applied. To keep the example tractable, only a subset of the options, uncertainties, and attributes are presented briefly here. For more detail, the reader is referred to Volume 1, Tabors et. al. (1989) and Connors (1989).

The AGREA study was performed on a regional level, aggregating all of New England's utilities into a single large service territory, with a twenty year planning horizon. The Advisory Group, consisting of utility executives, regulators, and industrial customers, identified two issues of particular

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[1] These four stages collapse into the two primary components of scenario analysis and trade off analysis discussed earlier.

[2] Some of the stages could clearly be used in the other steps, if so desired. For example, the exogenous constraints stage could in concept be applied prior to the scenario simulation step. However, since the exogenous constraints are identified using simulated attribute values, applying this stage earlier would require that a different measure of feasibility be utilized.

concern: the reliability of the electricity system and the advantages and disadvantages of increasing the use of natural gas as a fuel for electric power generation.

The following four options were considered in the study:

- Maintain the present 20% planning reserve margin
- Increase the planning reserve margin to 25%
- Build only natural gas fired supply additions (Gas Dependent)
- Build a mix of natural gas and coal fired facilities (Diversified)

These options were combined into four strategies: Gas Dependent with a 20% reserve margin (Gas20), Gas Dependent with a 25% reserve margin (Gas25), Diversified with a 20% reserve margin (Div20), and Diversified with a 25% reserve margin (Div25).[1]

A range of attributes were defined to measure the impact on cost of service, the environment, the reliability of service, and dependency on natural gas. Six scalar attributes will be considered in the examples in this chapter:

- Social cost of electricity in ¢/kWh (measured as the total discounted cost of providing service divided by the total kWh generated over the 20 years)

- Forced Fuel Switching (FFS) in % (measured as the percent of natural gas desired for electricity generation but unavailable due to supply constraints)

[1] The specific technologies included in the strategies were: 250 MW dual fueled combined cycle units, 50 MW dual fueled combustion turbines, 30 MW natural gas fired steam boiler/cogenerators, and 500 MW coal fired fluidized bed combustion units. The construction leadtimes are, respectively, 4, 3, 3, and 10 years. The gas dependent strategies planned for 70% combined cycles, 20% combustion turbines, 10% steam boilers and no coal units. The diversified strategy had planning goals of 25% combined cycles, 15% combustion turbines, 10% steam boilers and 50% coal units, measured as a percent of MWs of new installed capacity.

• SO_2 Emissions in millions of tons (cumulative emissions from electric generating facilities over the planning period)

• Nox Emissions in millions of tons (cumulative emissions from electric generating facilities over the planning horizon)

• Suspended Particulates (SP) in millions of tons (cumulative over the twenty year period)

• Level 5 Danger Hours in hours (cumulative number of times that the power pool calls on all interruptible customers)

Both forced fuel switching and danger hours require additional explanation. Because of the limited capacity of the pipelines and the high demand for natural gas in the winter[1], all new gas fired capacity (with the exception of the steam boilers) was required to have dual fuel capability. In the event that gas is unavailable, No. 2 fuel oil (Oil2) is utilized instead. The forced fuel switching attribute measures the amount of gas that had to be replaced by Oil2 because of natural gas supply constraints. Since Oil2 is both dirtier and more expensive than gas in all of the scenarios analyzed in the study, the participants were interested in achieving a lower value for this attribute, all else constant.

The danger hour attribute was developed in response to Advisory Group members concern about the interpretation of traditional utility reliability measures, such as Loss Of Load Probability (LOLP) and unmet energy. Based on the New England Power Pool's (NEPOOL) Operating Procedure 4, we were able to develop and model an attribute (the danger hour) measuring the number of hours that NEPOOL would activate the eight levels of O.P. 4. Level 5 is the stage at which interruptible customers are called to curtail their

[1] Because of this high seasonal heating demand, new gas fired units were assumed to always use Oil2 during the four winter months. This fuel switching is planned and thus does not count toward the "forced" fuel switching total.

loads. From a customer's point of view this attribute is an excellent analytical tool for measuring both the reliability of service and the costs and benefits of entering into an interruptible contract with the utility.

A variety of uncertainties were discussed by the Advisory Group. Four important uncertainties were finally selected: the amount of natural gas available, fuel prices, peak electricity demand, and a regulatory constraint on the amount of new natural gas/oil capacity permitted.

Two natural gas availability cases were considered - base and additions. The Base case almost doubles the amount of natural gas available for electric power generation in the first three to four years of the study. In the latter portion of the planning horizon gas availability declines as the demand from the other sectors of the economy (assumed to have priority) grows. In the Additions case, two additional supply increases in natural gas capacity are modeled in the latter portion of the study[1].

Two fuel price trajectories were used in the analysis. The High/Uncoupled (H/U) schedule assumes that coal and nuclear fuel prices track with inflation, but natural gas and fuel oils escalate at 4.5% in real terms. In the Medium/Coupled (M/C) case all fuels escalate at 3% in real terms.

Four peak demand load growth trajectories were analyzed. The first, called CELT, is based on NEPOOL's annual report on Capacity, Energy, Loads, and Transmission (CELT). It has an average annual growth rate of about 2%. The

[1] All increases in supply were assumed to be available at the current cost of natural gas.

second, Boom-Bust (BB), has significant growth (above 4% per year) for the first half of the study period, but then tails off to a more moderate level. Finally, two demand side management cases based on the CELT trajectory but with an additional 2000 MW of demand side efforts are modeled in DSM1 and DSM2. In DSM1, this additional effort is phased in over a ten year period starting immediately. DSM2 is a more aggressive case, with the 2000 MW implemented by the early 1990's[1].

The regulatory uncertainty is assumed to occur in the form of a fuel use act limiting the use of oil and natural gas for the generation of electricity in new power plants. Two cases are modeled: No Act occurs (NA) and a Fuel Act is passed next year (FA). Since the lead time for coal plants (the other primary supply option considered) is significantly longer than those for oil and gas units, the main result of the fuel act is to constrain the utility's shorter term supply options.

The combination of these uncertainties results in 32 futures, outlined in Table 1. The simulations were completed and the results tabulated in a decision matrix. Table 2 is the decision matrix for the AGREA study. Notice the importance of grouping the strategies together across futures so that the strategies in each set are directly comparable, i.e. they are being tested under the same conditions. This set of results will provide the basis for the examples in the remainder of the chapter. The questions we will seek to answer are those that the Advisory Group and Analysis Team struggled to

[1] The name DSM may be somewhat misleading, since a lack of data required us to "assume" that the load reduction came at no cost. In some sense, this might be better treated as an economic downturn. However, a measure of economic distress (such as jobs lost, etc.) was not included among the attributes, which means that it might be difficult to capture the negative impacts of lower growth.

grapple with: How do the strategies compare with each other? Is there a choice that is particularly robust? What uncertainties play a major role and which can be largely ignored?

Table 1

Futures

1	Base M/C NA	CELT	17	Base M/C FA	CELT
2	Base M/C NA	BB	18	Base M/C FA	BB
3	Base M/C NA	DSM1	19	Base M/C FA	DSM1
4	Base M/C NA	DSM2	20	Base M/C FA	DSM2
5	Add M/C NA	CELT	21	Add M/C FA	CELT
6	Add M/C NA	BB	22	Add M/C FA	BB
7	Add M/C NA	DSM1	23	Add M/C FA	DSM1
8	Add M/C NA	DSM2	24	Add M/C FA	DSM2
9	Base H/U NA	CELT	25	Base H/U FA	CELT
10	Base H/U NA	BB	26	Base H/U FA	BB
11	Base H/U NA	DSM1	27	Base H/U FA	DSM1
12	Base H/U NA	DSM2	28	Base H/U FA	DSM2
13	Add H/U NA	CELT	29	Add H/U FA	CELT
14	Add H/U NA	BB	30	Add H/U FA	BB
15	Add H/U NA	DSM1	31	Add H/U FA	DSM1
16	Add H/U NA	DSM2	32	Add H/U FA	DSM2

Table 2

The AGREA Study Decision Matrix

Scenario		Society's Levlz Cost (¢/kWh)	Forced Fuel Switching % Total	Cumul. SO2 Emissions (MM Tons)	Cumul. NOx Emissions (MM Tons)	Cumul. SP Emissions (MM Tons)	Cum. OP 4 Level 5 Danger Hrs
Future	Strategy						
1	Gas and 20%	8.13	29.0	6.40	3.35	5.10	492
Base M/C NA	Gas and 25%	8.18	31.3	6.11	3.27	5.03	72
CELT	Div and 20%	8.04	11.5	6.45	3.37	5.04	578
	Div and 25%	8.09	14.7	6.06	3.25	4.94	63
2	Gas and 20%	8.69	48.1	6.77	3.93	5.26	1256
Base M/C NA	Gas and 25%	8.72	49.3	6.53	3.85	5.19	930
BB	Div and 20%	8.60	39.5	6.64	3.89	5.13	1231
	Div and 25%	8.68	43.9	6.33	3.79	5.07	961
3	Gas and 20%	7.84	14.7	6.21	3.08	5.03	430
Base M/C NA	Gas and 25%	7.86	16.6	6.05	3.03	4.99	125
DSM1	Div and 20%	7.83	7.7	6.15	3.06	4.99	339
	Div and 25%	7.86	10.7	5.94	3.00	4.94	100
4	Gas and 20%	7.82	11.0	6.40	3.20	5.08	710
Base M/C NA	Gas and 25%	7.84	13.0	6.12	3.10	5.01	110
DSM2	Div and 20%	7.82	3.1	6.23	3.15	4.99	440
	Div and 25%	7.85	4.5	6.06	3.10	4.95	141
5	Gas and 20%	7.86	3.7	6.32	3.27	5.06	492
Add M/C NA	Gas and 25%	7.89	5.3	6.03	3.18	4.98	72
CELT	Div and 20%	7.94	0.0	6.43	3.34	5.03	578
	Div and 25%	7.95	0.0	6.02	3.20	4.92	63
6	Gas and 20%	8.40	27.4	6.67	3.82	5.20	1256
Add M/C NA	Gas and 25%	8.43	29.2	6.43	3.74	5.13	930
BB	Div and 20%	8.31	15.7	6.54	3.78	5.07	1231
	Div and 25%	8.38	21.6	6.24	3.68	5.01	961
7	Gas and 20%	7.71	0.0	6.18	3.05	5.01	430
Add M/C NA	Gas and 25%	7.72	0.0	6.01	2.99	4.97	125
DSM1	Div and 20%	7.77	0.0	6.13	3.05	4.98	339
	Div and 25%	7.78	0.0	5.92	2.98	4.92	100
8	Gas and 20%	7.72	0.0	6.38	3.17	5.06	710
Add M/C NA	Gas and 25%	7.72	0.0	6.09	3.07	4.99	110
DSM2	Div and 20%	7.80	0.0	6.23	3.15	4.99	440
	Div and 25%	7.81	0.0	6.05	3.09	4.94	141
9	Gas and 20%	8.52	29.4	6.48	3.40	5.28	492
Base H/U NA	Gas and 25%	8.55	31.0	6.22	3.32	5.22	72
CELT	Div and 20%	8.17	11.0	6.57	3.42	5.22	578
	Div and 25%	8.16	12.7	6.19	3.31	5.11	63
10	Gas and 20%	9.24	48.3	6.83	3.97	5.44	1256
Base H/U NA	Gas and 25%	9.26	49.3	6.60	3.89	5.38	930
BB	Div and 20%	8.82	38.1	6.76	3.94	5.30	1231
	Div and 25%	8.93	42.2	6.47	3.85	5.24	961
11	Gas and 20%	8.13	15.8	6.30	3.13	5.21	430
Base H/U NA	Gas and 25%	8.14	17.2	6.14	3.08	5.17	125
DSM1	Div and 20%	7.98	7.7	6.25	3.12	5.17	339
	Div and 25%	8.00	9.9	6.05	3.05	5.12	100
12	Gas and 20%	8.13	12.8	6.47	3.24	5.25	710
Base H/U NA	Gas and 25%	8.13	13.8	6.20	3.15	5.18	110
DSM2	Div and 20%	7.94	3.4	6.34	3.21	5.16	440
	Div and 25%	7.96	4.6	6.17	3.15	5.12	141

Table 2

The AGREA Study Decision Matrix (Continued)

Scenario		Society's Leviz Cost (¢/kWh)	Forced Fuel Switching % Total	Cumul. SO2 Emissions (MM Tons)	Cumul. NOx Emissions (MM Tons)	Cumul. SP Emissions (MM Tons)	Cum. OP 4 Level 5 Danger Hrs
Future	Strategy						
13 Add H/U NA CELT	Gas and 20%	8.18	4.0	6.41	3.31	5.24	492
	Gas and 25%	8.18	5.1	6.14	3.23	5.17	72
	Div and 20%	8.05	0.0	6.54	3.39	5.20	578
	Div and 25%	8.01	0.0	6.16	3.27	5.09	63
14 Add H/U NA BB	Gas and 20%	8.88	27.8	6.73	3.85	5.38	1256
	Gas and 25%	8.89	29.2	6.51	3.78	5.32	930
	Div and 20%	8.46	14.1	6.67	3.83	5.24	1231
	Div and 25%	8.56	19.3	6.37	3.74	5.18	961
15 Add H/U NA DSM1	Gas and 20%	7.96	0.0	6.27	3.09	5.19	430
	Gas and 25%	7.95	0.0	6.11	3.04	5.15	125
	Div and 20%	7.91	0.0	6.24	3.10	5.16	339
	Div and 25%	7.90	0.0	6.03	3.03	5.11	100
16 Add H/U NA DSM2	Gas and 20%	7.98	0.0	6.44	3.21	5.23	710
	Gas and 25%	7.96	0.0	6.17	3.11	5.16	110
	Div and 20%	7.91	0.0	6.33	3.20	5.16	440
	Div and 25%	7.91	0.0	6.16	3.14	5.11	141
17 Base M/C FA CELT	Gas and 20%	8.04	1.7	6.63	3.45	5.06	1362
	Gas and 25%	8.08	7.1	6.26	3.33	4.97	323
	Div and 20%	8.05	2.1	6.67	3.46	5.06	1291
	Div and 25%	8.07	4.4	6.27	3.33	4.95	294
18 Base M/C FA BB	Gas and 20%	8.68	33.1	6.70	3.95	5.09	1369
	Gas and 25%	8.72	34.1	6.50	3.87	5.03	914
	Div and 20%	8.53	29.8	6.86	3.97	5.12	1638
	Div and 25%	8.59	32.6	6.60	3.90	5.06	993
19 Base M/C FA DSM1	Gas and 20%	7.80	0.3	6.35	3.13	5.02	931
	Gas and 25%	7.84	0.0	6.25	3.12	4.98	643
	Div and 20%	7.80	0.3	6.35	3.13	5.02	933
	Div and 25%	7.83	0.5	6.27	3.11	5.00	859
20 Base M/C FA DSM2	Gas and 20%	7.90	0.0	6.32	3.22	4.98	534
	Gas and 25%	7.90	0.0	6.01	3.11	4.91	126
	Div and 20%	7.86	0.0	6.41	3.23	5.01	703
	Div and 25%	7.86	1.5	6.14	3.14	4.95	146
21 Add M/C FA CELT	Gas and 20%	8.03	0.0	6.63	3.44	5.05	1362
	Gas and 25%	8.02	0.0	6.25	3.31	4.96	323
	Div and 20%	8.04	0.0	6.67	3.46	5.05	1291
	Div and 25%	8.03	0.0	6.26	3.32	4.95	294
22 Add M/C FA BB	Gas and 20%	8.43	10.7	6.62	3.86	5.04	1369
	Gas and 25%	8.48	11.9	6.42	3.77	4.98	914
	Div and 20%	8.30	7.7	6.78	3.88	5.07	1638
	Div and 25%	8.33	9.4	6.52	3.80	5.01	993
23 Add M/C FA DSM1	Gas and 20%	7.80	0.0	6.35	3.13	5.02	931
	Gas and 25%	7.84	0.0	6.25	3.12	4.98	643
	Div and 20%	7.80	0.0	6.35	3.13	5.02	933
	Div and 25%	7.83	0.0	6.27	3.11	5.00	859
24 Add M/C FA DSM2	Gas and 20%	7.90	0.0	6.32	3.22	4.98	534
	Gas and 25%	7.90	0.0	6.01	3.11	4.91	126
	Div and 20%	7.86	0.0	6.41	3.23	5.01	703
	Div and 25%	7.85	0.0	6.14	3.13	4.95	146

Table .2

The AGREA Study Decision Matrix (Continued)

Scenario Future	Scenario Strategy	Society's Leviz Cost (¢/kWh)	Forced Fuel Switching % Total	Cumul. SO2 Emissions (MM Tons)	Cumul. NOx Emissions (MM Tons)	Cumul. SP Emissions (MM Tons)	Cum. OP 4 Level 5 Danger Hrs
25	Gas and 20%	8.04	1.3	6.76	3.51	5.22	1362
Base H/U FA	Gas and 25%	8.06	4.8	6.40	3.40	5.14	323
CELT	Div and 20%	8.05	2.1	6.79	3.52	5.22	1291
	Div and 25%	8.04	3.5	6.40	3.40	5.12	294
26	Gas and 20%	8.53	26.1	6.94	4.05	5.23	1369
Base H/U FA	Gas and 25%	8.57	27.0	6.75	3.98	5.18	914
BB	Div and 20%	8.58	27.0	7.00	4.04	5.27	1639
	Div and 25%	8.61	29.1	6.76	3.97	5.21	993
27	Gas and 20%	7.91	0.4	6.44	3.18	5.20	931
Base H/U FA	Gas and 25%	7.88	0.0	6.38	3.18	5.16	643
DSM1	Div and 20%	7.91	0.4	6.44	3.18	5.19	933
	Div and 25%	7.89	0.5	6.38	3.17	5.17	859
28	Gas and 20%	7.88	0.0	6.44	3.28	5.16	534
Base H/U FA	Gas and 25%	7.87	0.0	6.14	3.18	5.07	126
DSM2	Div and 20%	7.89	0.1	6.52	3.29	5.18	704
	Div and 25%	7.92	1.5	6.25	3.19	5.12	147
29	Gas and 20%	8.03	0.0	6.76	3.51	5.22	1362
Add H/U FA	Gas and 25%	8.01	0.0	6.39	3.39	5.13	323
CELT	Div and 20%	8.03	0.0	6.79	3.52	5.22	1291
	Div and 25%	8.00	0.0	6.40	3.39	5.12	294
30	Gas and 20%	8.36	11.4	6.89	4.00	5.20	1369
Add H/U FA	Gas and 25%	8.40	12.6	6.70	3.92	5.15	914
BB	Div and 20%	8.32	7.2	6.93	3.96	5.23	1639
	Div and 25%	8.33	8.3	6.69	3.88	5.17	993
31	Gas and 20%	7.91	0.0	6.44	3.18	5.20	931
Add H/U FA	Gas and 25%	7.88	0.0	6.38	3.18	5.16	643
DSM1	Div and 20%	7.91	0.0	6.44	3.18	5.19	933
	Div and 25%	7.89	0.0	6.38	3.17	5.17	859
32	Gas and 20%	7.88	0.0	6.44	3.28	5.16	534
Add H/U FA	Gas and 25%	7.87	0.0	6.14	3.18	5.07	126
DSM2	Div and 20%	7.89	0.0	6.52	3.29	5.18	704
	Div and 25%	7.90	0.0	6.25	3.19	5.12	147

Section 4 A Priori Information Elicitation

The a priori information elicitation stage serves to help the participant probe his/her preferences, as well as those of the wider Advisory Group, from among the possible attributes, uncertainties and strategies. The MATOF framework is best utilized as an integral and interactive part of an on-going IRP process[1]. Given such an approach, the information elicitation stage serves as the connecting bridge with the more formal analysis of the scenario simulation results. There are two issues that should be jointly addressed in this preliminary stage: 1) ensuring an adequate understanding of the integrated resource planning process and 2) the elicitation of a priori beliefs, convictions and requirements.

The first step of the a priori stage should focus on introducing the IRP concepts and non-optimization mindset, stressing definitions (such as those presented in Section 1), reviewing issues of concern, developing lists of strategies, attributes, and uncertainties, and developing the scenarios. This type of exercise should be performed with the group as a whole prior to beginning the MATOF analysis, and again as results of the trade off analysis become available. The goal is to familiarize the participant with the process and to help build a strong analysis structure working within the rules of the game. Every participant involved in the process has equal opportunity to suggest input and the other members must be tolerant of this right.

[1]MATOF could also serve as an analysis tool for someone outside the process after a study is completed. In this case, the information elicitation stage serves to familiarize the user with the study parameters and to prepare them for the analysis by helping them to think consistently about their preferences and concerns.

As a result of this approach, the strategies, uncertainties, and attributes reflect the concerns of a large and diverse group. This means that many of the strategies and attributes may be unimportant to an individual participant. This type of information can be used to shape the data analysis procedure. Thus, the second function of this stage is to have the participant (and the analyst if people are working in teams) think about their preferences, assumptions, and requirements. The list of questions that the participant should focus on as a guide in thinking systematically about these issues should include:

1) Is more or less of each attribute always preferred?

2) A priori, can you define any critical levels or non-linearities in your preferences for attribute levels?

3) Which attributes are especially important to you?

4) Are there any options or strategies that you are particularly interested in? Any that you particularly dislike?

5) Can you (and do you wish to) assign probabilities to the futures? Are there any futures that you find particularly (un)likely? Why?

Questions 1 and 2 are designed to elicit information describing the participant's beliefs about the "characteristics" of each of the attributes, rather than preferences (which are addressed in Question 3). This information is not meant to be used to develop utility functions or weights, but to help the participants think "consistently" about the trade offs. Question 1 addresses the more (or less) is always better assumption that is often made in utility analysis. Most of the attributes in utility planning should be of this monotonic nature. An example of a non-monotonic attribute is one in which there is a "right" amount - below this level one might have a monotonically increasing preference for this attribute, above it a monotonically decreasing function.

The last three questions probe the participant's a priori interest in the strategies, attributes, and uncertainties. This information should be circulated (in an anonymous fashion, if necessary)[1]. Such information circulation is important because one of the primary goals of the IRP process is to have participants think about the impacts of strategies on attributes that <u>others</u> care about. At some level such information sharing has already occurred as the participants bared their souls in suggesting strategies, attributes, and uncertainties in the first step of this stage. However, a more precise and consistent evaluation of individual parameters is required before undertaking the trade off analysis. These questions are designed to accomplish this goal.

Another useful outcome of this careful a priori review and Question 5 is the initialization of the trade off analysis. The evaluation of trade offs is an extremely difficult process to undertake and it can be convenient to have the participant initially focus on a limited subset of plans. An initial subset might be suggested by the sorting and efficient set stage later in MATOF. However, since many of the participants will strongly favor certain strategies over others, a useful place to start the trade off analysis is to compare two that a decision maker feels strongly about a priori.

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[1] One simple method to do this would be to have each participant select the three attributes they care most deeply about. The number of responses for each attribute could be tabulated - either as the number of times selected or perhaps using a more complicated weighting procedure. This should be repeated at least once after the initial data analysis, since preferences may change if attributes are stable regardless of alternatives or uncertainties.

Finally, Question 6 addresses the issue of some futures being more likely than others. The problems inherent in deriving meaningful probabilities for the set of futures required that MATOF be designed to function whether or not probabilities are available. The tools will be presented for both cases: 1) assuming that no probabilities have been assessed, i.e. all futures are implicitly assumed to be equally likely, and 2) probabilities have been assessed and the participant is interested in using them. These two cases will be denoted as the uniform and non-uniform probabilities cases, respectively. If no formal probabilities are available, it is still useful if the participant is able to indicate some futures that he/she perceives to have a higher or lower likelihood of occurring.

Section 4.1 Example: A Priori Information Elicitation

This example will focus on the second step of this stage - the elicitation of a priori beliefs about the strategies, uncertainties, and attributes analyzed in the AGREA study[1]. I will present my thoughts on the questions listed in the previous section. All of the examples used to demonstrate the trade off tools and framework are based on my analysis, framed to best illuminate the concepts, and do not necessarily reflect the views of the Energy Laboratory or the AGREA team.

1) Is more or less of each attribute always preferred?

[1] The development of the scenarios is explained in detail in Connors, 1989.

For all six of the attributes presented in Section 3 - cost, forced fuel switching, SO2, NOx and Suspended Particulates emissions, and Level 5 Danger Hours - I will always prefer less of a particular attribute, everything else held constant.

2) A priori, can you define any critical levels or non-linearities in your preferences for attribute levels?

My knowledge of NOx and SP emissions and forced fuel switching is limited so I do not feel comfortable specifying any critical levels. My preferences are definitely non-linear, however, since I see myself tolerating smaller values for environmental attributes but becoming very concerned as these levels reach some as yet unspecified (mainly because of lack of data) critical levels.

Because I have a baseline for cost - the 1988 electricity price forecast of NEPOOL's planning department [NEPLAN 1988] - I feel comfortable setting a critical level for cost at 8.28 ¢/kWh[1]. Since NEPLAN's forecast is based on a single set of assumptions about future parameter values, I have no intention of rejecting all strategies with costs above that level. But it does act as a benchmark against which to compare the results.

In 1987, NEPOOL experienced about 35 level 5 danger hours. Since the summer of that year was particularly hot and the system had significant trouble, it seems reasonable to try and keep the 20 year cumulative Level 5 danger hours below 500, if possible. This is also definitely a non-linear preference - as the system reaches above 1,000 or 1,500 danger hours one can

[1] This figure is calculated by taking the average of NEPLAN's forecast (in constant 1988 dollars). Since the forecast extends only to 2003, the remaining portion of AGREA's 20 year planning horizon is estimated by using a growth rate equal to the average of the last four years of NEPLAN's forecasts.

imagine significant repercussions from the industrial sector, in the form of self-generation of electricity, relocation or a loss of goodwill.

Fay and Golomb [1982] estimate the SO2 emissions due to electric power generation in New England to be on the order of 395,000 tons/year. Over twenty years this would be almost 8,000,000 tons of SO2. Since I believe that current emission levels are too high, I would like to see this reduced by at least twenty percent, or to a level of 6,400,000 cumulative tons of emissions.

3) Which attributes are especially important to you?

Cost, reliability and the environmental emissions attributes are all important to me. Of the three environmental attributes, SO2 is probably the most important because I am familiar with and care about the problems it causes. I think forced fuel switching is a proxy attribute for cost and environmental impacts, especially given the assumptions about natural gas made in the study. In this case it is more appropriate to focus on cost and SO2 directly and I will tend to disregard forced fuel switching for this reason.

4) Are there any options or strategies that you are particularly interested in? Any that you particularly dislike?

My intuition suggests that the diversified and 25% reserve margin case will perform well. On the other hand, the prevailing policy is towards natural gas fired units (if anything is built) and maintaining the 20% reserve margin. Therefore I am particularly interested in comparing these two.

5) Can you (and do you wish to) assign probabilities to the futures? Are there any futures that you find particularly (un)likely? Why?

I do not think it is possible to assign meaningful probabilities to all 32 futures. However, I think that one can assess personal ordinal rankings for the uncertainties. For example, I feel that Base case gas availability is more likely than the Additions case; that the CELT and DSM1 demand forecasts are more likely to occur than the other cases; that the Fuel Act has very little chance of being enacted; and that the Medium/Coupled fuel trajectory is more reasonable over the planning period than the High/Uncoupled case.

Given this information, I can now proceed to the analysis stage. To summarize, I have decided to focus on cost, reliability, and SO2 as my major concerns, with NOx and SP emissions as second level attributes. I have defined critical levels for these attributes, examined my beliefs about the chance that the various uncertainties will occur and have selected a subset of strategies for the first cut of the trade off analysis.

Section 5 Exogenous Constraints

It is possible that the construction and simulation of scenarios will result in attribute values that violate some exogenous constraints on the system. The type of exogenous constraint envisioned here must be clearly distinguished from a value preference for an attribute level that is viewed by some participants as being too high or too low. These exogenous constraints must be outside the reasonable control of the decision makers. A good example of an exogenous constraint would be federally imposed environmental emission restrictions. An example of a value preference would be a participant suggesting that a cost of 12 ¢/kWh is too high and proposing to eliminate all strategies that fail to meet this target.

This stage could be completed earlier by the analysis team without involving the participants. However, particularly when there are only a limited number of strategies being considered or there is significant controversy about the choices, it is better that this be an explicit stage of the analysis and trade off framework that the participants are working with.. The flow of information is more direct - the participants are involved and understand why certain strategies must be eliminated or revised before being considered further.

It is unclear whether many of these types of exogenous constraints already exist today, except, as noted above, local and regional emissions constraints. Effectively measuring any such constraints will depend on appropriately defined attributes. For example, an attribute representing twenty year totals for regional emission numbers will not allow the decision makers to discard plans that violate standards on a local level or in a particular subset of the planning period.

The exogenous constraints procedure is simple. Eliminate from further consideration all strategies that have "infeasible" attributes. In the uniform probabilities case for the futures, a single occurrence of an infeasible attribute could be enough to require elimination, although it would be easy to set a higher threshold. If probabilities are available, a strategy would only be dropped if it was infeasible in a set of futures for which the aggregate probability was greater than a specified threshold. This level might well depend on which attribute constraint was violated and on the seriousness of the consequences.

The strategies (if any) that are eliminated at this stage might prove useful at a later point. Should the remaining stages of the analysis fail to uncover a strategy that is robust, the plans discarded at the exogenous constraints stage will warrant further analysis. This is particularly true if the constraint is one that the decision makers might be able to exert some influence towards making less constricting.

Section 5.1 Example: Exogenous Constraints

The 1988 AGREA study did not result in the development of attributes that are suited to the application of exogenous constraints. For purposes of example only (the results of this example, unlike the others, will not be carried forward through the analysis), let us assume that the federal government has placed a restriction on the amount of SO2 emitted in New England over the next twenty years and that the portion allotted to electric power generation must be less than 7,000,000 tons.

Table 3 shows the decision matrix (containing only the SO2 attribute) with a column selecting all the strategies that violate the assumed emissions constraint. Div20 is the only strategy that violates this limit and it does so once, in the future with more limited gas availability, high/uncoupled fuel prices, a fuel act, and high load growth (BB).

Table 3

Example of an Exogenous Constraint

Scenario: Future	Scenario: Strategy	Cumulative SO2 Emissions (MM Tons)	SORT Greater than 7.00
1	Gas and 20%	6.40	
Base M/C NA	Gas and 25%	6.11	
CELT	Div and 20%	6.46	
	Div and 25%	6.06	
2	Gas and 20%	6.77	
Base M/C NA	Gas and 25%	6.53	
BB	Div and 20%	6.64	
	Div and 25%	6.33	
3	Gas and 20%	6.21	
Base M/C NA	Gas and 25%	6.05	
DSM1	Div and 20%	6.15	
	Div and 25%	5.94	
4	Gas and 20%	6.40	
Base M/C NA	Gas and 25%	6.12	
DSM2	Div and 20%	6.23	
	Div and 25%	6.06	
5	Gas and 20%	6.32	
Add M/C NA	Gas and 25%	6.03	
CELT	Div and 20%	6.43	
	Div and 25%	6.02	
6	Gas and 20%	6.67	
Add M/C NA	Gas and 25%	6.43	
BB	Div and 20%	6.54	
	Div and 25%	6.24	
7	Gas and 20%	6.16	
Add M/C NA	Gas and 25%	6.01	
DSM1	Div and 20%	6.13	
	Div and 25%	5.92	
8	Gas and 20%	6.36	
Add M/C NA	Gas and 25%	6.09	
DSM2	Div and 20%	6.23	
	Div and 25%	6.05	
9	Gas and 20%	6.46	
Base H/U NA	Gas and 25%	6.22	
CELT	Div and 20%	6.57	
	Div and 25%	6.19	
10	Gas and 20%	6.83	
Base H/U NA	Gas and 25%	6.60	
BB	Div and 20%	6.76	
	Div and 25%	6.47	
11	Gas and 20%	6.30	
Base H/U NA	Gas and 25%	6.14	
DSM1	Div and 20%	6.25	
	Div and 25%	6.05	
12	Gas and 20%	6.47	
Base H/U NA	Gas and 25%	6.20	
DSM2	Div and 20%	6.34	
	Div and 25%	6.17	
13	Gas and 20%	6.41	
Add H/U NA	Gas and 25%	6.14	
CELT	Div and 20%	6.54	
	Div and 25%	6.18	
14	Gas and 20%	6.73	
Add H/U NA	Gas and 25%	6.51	
BB	Div and 20%	6.67	
	Div and 25%	6.37	
15	Gas and 20%	6.27	
Add H/U NA	Gas and 25%	6.11	
DSM1	Div and 20%	6.24	
	Div and 25%	6.03	
16	Gas and 20%	6.44	
Add H/U NA	Gas and 25%	6.17	
DSM2	Div and 20%	6.33	
	Div and 25%	6.19	
17	Gas and 20%	6.63	
Base M/C FA	Gas and 25%	6.26	
CELT	Div and 20%	6.67	
	Div and 25%	6.27	
18	Gas and 20%	6.70	
Base M/C FA	Gas and 25%	6.50	
BB	Div and 20%	6.86	
	Div and 25%	6.60	
19	Gas and 20%	6.35	
Base M/C FA	Gas and 25%	6.25	
DSM1	Div and 20%	6.36	
	Div and 25%	6.27	
20	Gas and 20%	6.32	
Base M/C FA	Gas and 25%	6.01	
DSM2	Div and 20%	6.41	
	Div and 25%	6.14	
21	Gas and 20%	6.63	
Add M/C FA	Gas and 25%	6.25	
CELT	Div and 20%	6.67	
	Div and 25%	6.26	
22	Gas and 20%	6.62	
Add M/C FA	Gas and 25%	6.42	
BB	Div and 20%	6.79	
	Div and 25%	6.52	
23	Gas and 20%	6.36	
Add M/C FA	Gas and 25%	6.25	
DSM1	Div and 20%	6.36	
	Div and 25%	6.27	
24	Gas and 20%	6.32	
Add M/C FA	Gas and 25%	6.01	
DSM2	Div and 20%	6.41	
	Div and 25%	6.14	
25	Gas and 20%	6.76	
Base H/U FA	Gas and 25%	6.40	
CELT	Div and 20%	6.79	
	Div and 25%	6.40	
26	Gas and 20%	6.94	
Base H/U FA	Gas and 25%	6.75	
BB	Div and 20%	7.00	Div and 20%
	Div and 25%	6.76	
27	Gas and 20%	6.44	
Base H/U FA	Gas and 25%	6.36	
DSM1	Div and 20%	6.44	
	Div and 25%	6.39	
28	Gas and 20%	6.44	
Base H/U FA	Gas and 25%	6.14	
DSM2	Div and 20%	6.52	
	Div and 25%	6.25	
29	Gas and 20%	6.76	
Add H/U FA	Gas and 25%	6.39	
CELT	Div and 20%	6.79	
	Div and 25%	6.40	
30	Gas and 20%	6.86	
Add H/U FA	Gas and 25%	6.70	
BB	Div and 20%	6.93	
	Div and 25%	6.69	
31	Gas and 20%	6.44	
Add H/U FA	Gas and 25%	6.38	
DSM1	Div and 20%	6.44	
	Div and 25%	6.38	
32	Gas and 20%	6.44	
Add H/U FA	Gas and 25%	6.14	
DSM2	Div and 20%	6.52	
	Div and 25%	6.25	

There are two decision rules that could be implemented at this point. First, the stricter case, eliminate the Div20 strategy from the active list of choices because it failed at least once (regardless of the likelihood of the future or the magnitude of the failure). The other, perhaps more reasonable approach, is to consider both the probability of the constraint being violated and whether it is "significant". In this case, given my personal assessment of the likelihood of future 26 (three of the four uncertainty values are in my a priori less likely group) and the margin of violation, my recommendation would be to maintain Div20 in the data base.

Section 6 Attribute Variability Analysis

The goal of the attribute variability analysis stage is to gain a detailed understanding of the attribute vectors in the decision matrix. There are two major steps in this stage. First, the participant should look at the variation of the attributes across all futures and strategies. Second, a more focused view is taken by reviewing attribute variation for each strategy across all the futures.

In order to effectively understand the nature of the trade offs involved between different strategies, a participant must first review the attribute results in a global way. It is difficult to appreciate the size of a trade off until it is placed in the context of the attribute's variation across the decision matrix. Two types of variation analysis are suggested in this section. First, the variation of the attributes across all strategies and all futures should be measured. Although this is a useful indication of global variation, it is inappropriate to use this as a sole measure of variability because many, if not all, of the strategies will be mutually exclusive. Because of this, we must also measure the variability of attributes for each possible strategy across all futures. Let us denote these measures as global and strategy specific attribute variability, respectively.

Global attribute variation measures use all of the data in the decision matrix for each attribute. In the example in Table 2, the measures about to be described would be applied to all of the results listed in the column under each attribute. In general, such an aggregation is not appropriate. However, the only goal at this point is to allow the participant to place the magnitudes of the trade offs analyzed later in context. Strategy specific attribute variation analysis must be done for each attribute and strategy, across all possible futures. In Table 2, for example, a strategy specific attribute variation analysis would look at the attribute results for gas-dependent 20% reserve margin cases across all 32 futures. Clearly, if there are n attributes and m strategies, then n global and m*n strategy specific attribute analyses must be completed.

The same measures of variability are applicable in both cases. The following measures are suggested:

1) A histogram

2) The expected value (i.e. the mean)

3) Maximum and minimum occurring values and the futures in which they occur

4) Standard Deviation and coefficient of variation

The histogram is a visual tool for measuring variability, which also gives an indication of the nature of the distribution of the results. It is simply a tabulation of the number of occurrences of an attribute value within a particular interval, called a bin. Probabilities could be incorporated by using the probability value as the bin input, as opposed to the value 1 used in the uniform future distribution case. This would result in a probability distribution function (pdf) for the attribute. A pdf for the uniform case could be created by using the value 1/n (where n is the number of futures) as the bin counting value.

The expected value, maximum, and minimum of an attribute are parameter values that assist in anchoring the distribution and help in comparing the strategy specific attribute variations. However, it is clear that a measure of dispersion is also required, since two very different distributions can have the same mean, minimum and maximum. The standard deviation is traditionally used. The standard deviation, however, is an absolute measure of dispersion. For purposes of comparison between attributes (and even within attributes if the magnitude of the results is significantly different), a relative measure is required. The coefficient of variation (CV) for a data set is defined as the standard deviation of that data divided by its mean.

The types of questions that a participant should be asking as she or he reviews this output include:

1) What do the histograms suggest about the pdfs of the attributes? Do they appear to be significantly different as the strategies are changed?

2) Are there any attributes that have substantial variation? No variation?

3) Based on this first review of the achievable attribute values and their dispersion, would you set any new "critical" levels?

4) Reviewing the strategy specific attribute analyses, are there any strategies that "appear" to be particularly interesting or disappointing?

Question 2 is particularly important, for less obvious reasons. It may well occur that an attribute will have only a small deviation across all the strategies and futures, but is defined in such a manner that a very small change in magnitude has a large impact. A regionally and temporally aggregated cost number will have this property. The participant must not be overawed by wild swings or apparent stability in attributes without carefully considering the attributes and their definitions. This underscores the importance of the a priori information elicitation stage. Attributes with low variability but high impacts will also become a consideration in selecting scaling techniques in later sections should scaling be used in order to compare strategies across attributes with very different units and magnitudes.

The remaining three questions listed above are suggested as a framework within which the participant can familiarize themselves with the data and begin to think about what trade offs might be important, given what is achievable in terms of attribute values.

Section 6.1 Example: Attribute Variability

We begin with the global attribute variability analysis. Table 4 displays the tabulated results for the mean, maximum and the dispersion measures. The histograms are shown in Figures 2 to 4. For brevity's sake, let us focus only on the attributes of cost, SO2 and Level 5 danger hours.

The histogram for cost (Figure 2) indicates a very one-sided distribution. The entire range spans from 7.7 ¢/kWh to 9.26 ¢/kWh - however, only about 30 of 128 scenarios modeled fell above 8.2 ¢/kWh. The remaining values are tightly distributed around 8 cents. It is important to consider that the regional definition of the attribute is closely tied to the scale of the impact. The AGREA team has calculated that a change of about 0.1 ¢/kWh is equivalent to about 2.5 billion dollars over the twenty year period.

<u>Figure 2</u>
Cost and Global

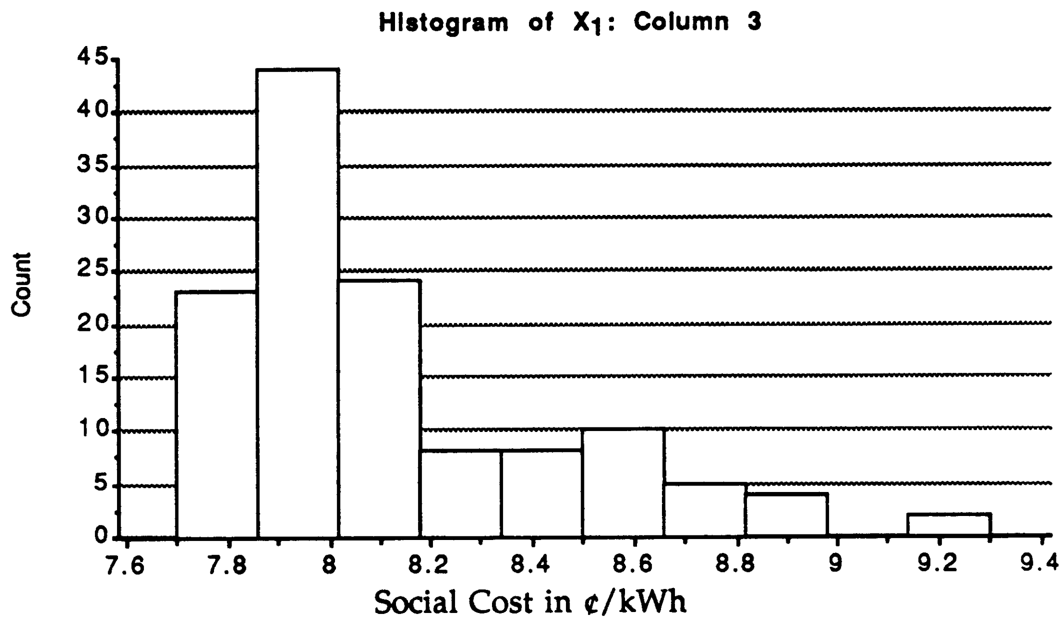


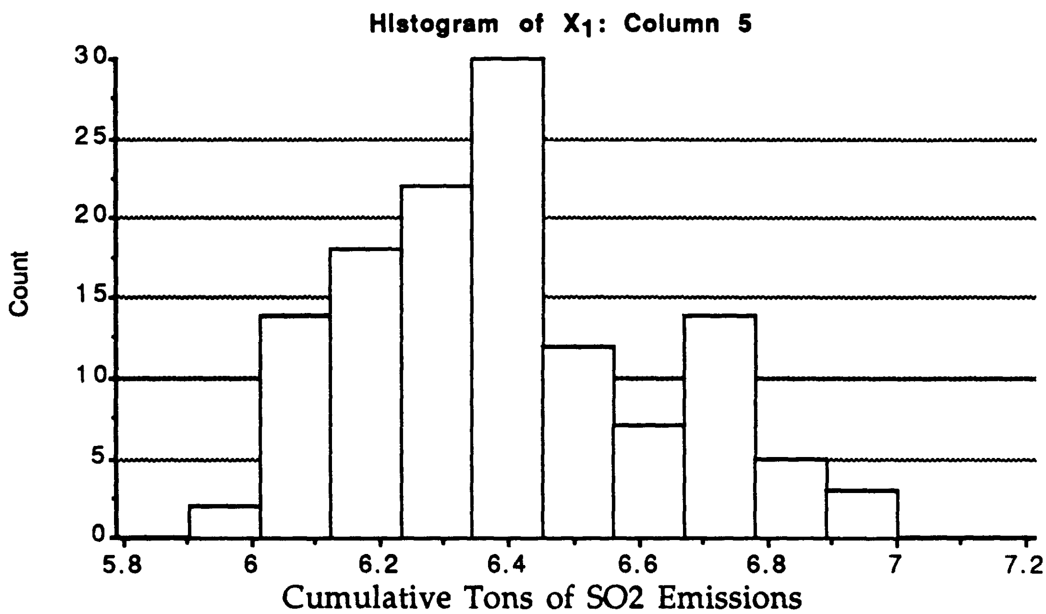
Table .4

Global and Strategy Specific Attribute Variability

	Attributes					
	Society's Leviz Cost (¢/kWh)	% Total MCF Forced Fuel Switching	Cumulative SO2 Emissions (MM Tons)	Cumulative NOx Emissions (MM Tons)	Cumulative SP Emissions (MM Tons)	Cum. OP 4 Activity Level 5 Danger Hrs
			Global			
Max	9.26	49.3	7.00	4.05	5.44	1639
Min	7.71	0.0	5.92	2.98	4.91	63
Mean	8.11	9.8	6.39	3.38	5.10	657
StDv	0.33	13.5	0.24	0.31	0.11	452
CV	0.04	1.38	0.04	0.09	0.02	0.69
			Gas20			
Max	9.24	48.3	6.94	4.05	5.44	1369
Min	7.71	0.0	6.18	3.05	4.98	430
Mean	8.13	11.2	6.51	3.42	5.15	885
StDv	0.37	14.7	0.20	0.32	0.11	380
CV	0.05	1.32	0.03	0.09	0.02	0.43
			Gas25			
Max	9.26	49.3	6.75	3.98	5.38	930
Min	7.72	0.0	6.01	2.99	4.91	72
Mean	8.15	12.1	6.27	3.34	5.09	405
StDv	0.38	15.1	0.21	0.31	0.12	350
CV	0.05	1.24	0.03	0.09	0.02	0.87
			Div20			
Max	8.82	39.5	7.00	4.04	5.30	1639
Min	7.77	0.0	6.13	3.05	4.98	339
Mean	8.07	7.1	6.51	3.42	5.12	894
StDv	0.28	11.3	0.23	0.32	0.10	437
CV	0.03	1.58	0.04	0.09	0.02	0.49
			Div25			
Max	8.93	43.9	6.76	3.97	5.24	993
Min	7.78	0.0	5.92	2.98	4.92	63
Mean	8.09	8.6	6.26	3.34	5.06	445
StDv	0.30	12.6	0.21	0.31	0.10	395
CV	0.04	1.46	0.03	0.09	0.02	0.89

Figure 3 indicates that the distribution for cumulative SO2 emissions (measured in millions of tons) is surprisingly normal, with a range of 5.9 to 7.0 million tons of emissions. If Fay and Golomb are correct, this range is equivalent to about three years of present SO2 emissions. The mean falls exactly on my a priori specified critical level of 6,400,000 tons - not by design, I should add.

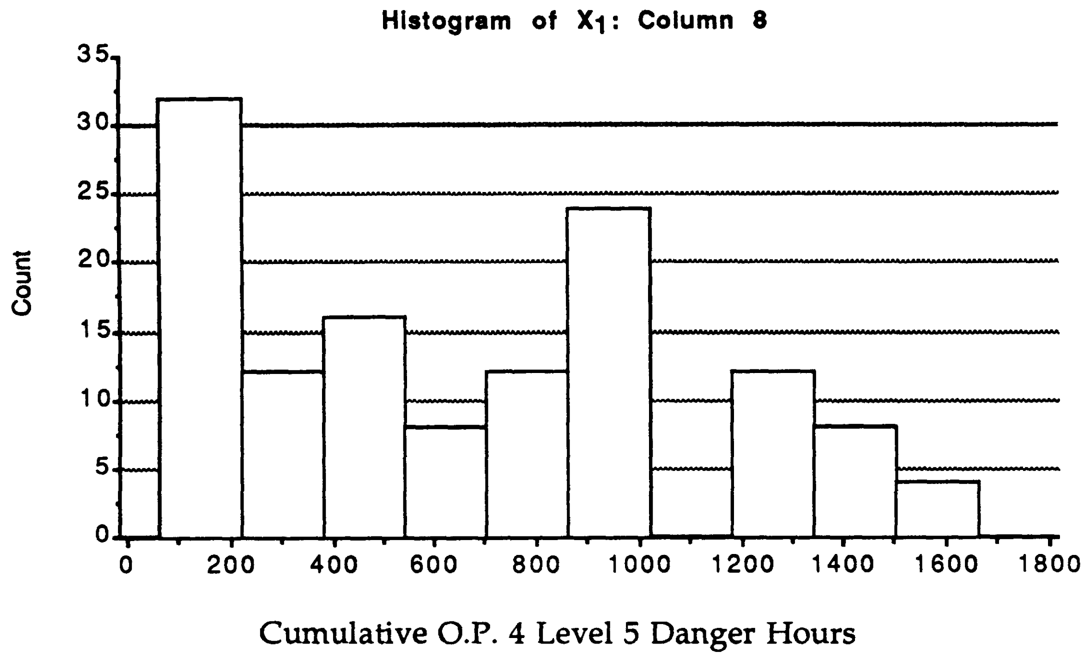
Figure 3
SO2 and Global



The global distribution of cumulative Level 5 danger hours (Figure 4) is best described as uniform, although there is some tendency towards the left. There is a very wide spread, ranging from 60 to above 1600, with a large number of scenarios falling above my pre-specified critical level of 500.

In summary, the global attribute analysis has given me little reason to change my pre-specified levels of concern for cost and SO2. The pre-specified value for Level 5 danger hours appears somewhat constraining, so we shall need to monitor that. There is a striking variation across DH5 outcomes, and much more stability for the cost (although this is somewhat misleading because of the scale) and SO2 attributes. With this information about the global performance of the attributes of interest, we can now take the first step towards evaluating the trade offs among the strategies by analyzing the strategy specific attribute variability.

Figure 4
DH5 and Global



The strategy specific attribute variation measures are also tabulated in Table 4. The histograms for cost are shown in Figures 5-8, those for SO2 emissions in Figures 9-12, and those for Level 5 danger hours in Figures 13-16.

The distributions of the strategy specific histograms for cost are similar in shape to that of the global histogram shown in Figure 2. The major noticeable difference is that the histograms for Gas20 and Gas25 are more dispersed for all four strategies (with both a higher maximum and lower minimum) than those for Div20 and Div25, as the standard deviation result suggests. The number of occurrences below 8.2 ¢/kWh are approximately the same across all four strategies - 24 for Div20 and Div25, 22 and 20 for Gas 20 and Gas25, respectively. (Note the different scales on the vertical axes.) The mean indicates that there is some penalty in cost for increasing the reserve margin, although this is difficult to discern from the histograms.

The statistics for the strategy specific attribute variation for SO2 emissions indicate that strategies incorporating a 25% planning reserve margin have lower emissions. The dispersion is quite similar, as measured by the standard deviation and the CV. The shape of the distribution changes markedly across the four strategies (see Figures 9-12): the Diversified cases maintain the normal shape of the global distribution, while the gas cases are much more skewed in shape. Most dramatic, however, is the pronounced trend to lower SO2 values exhibited by the 25% reserve margin strategies, perhaps a stronger tendency than the statistics in Table 4 suggest.

Figure 5

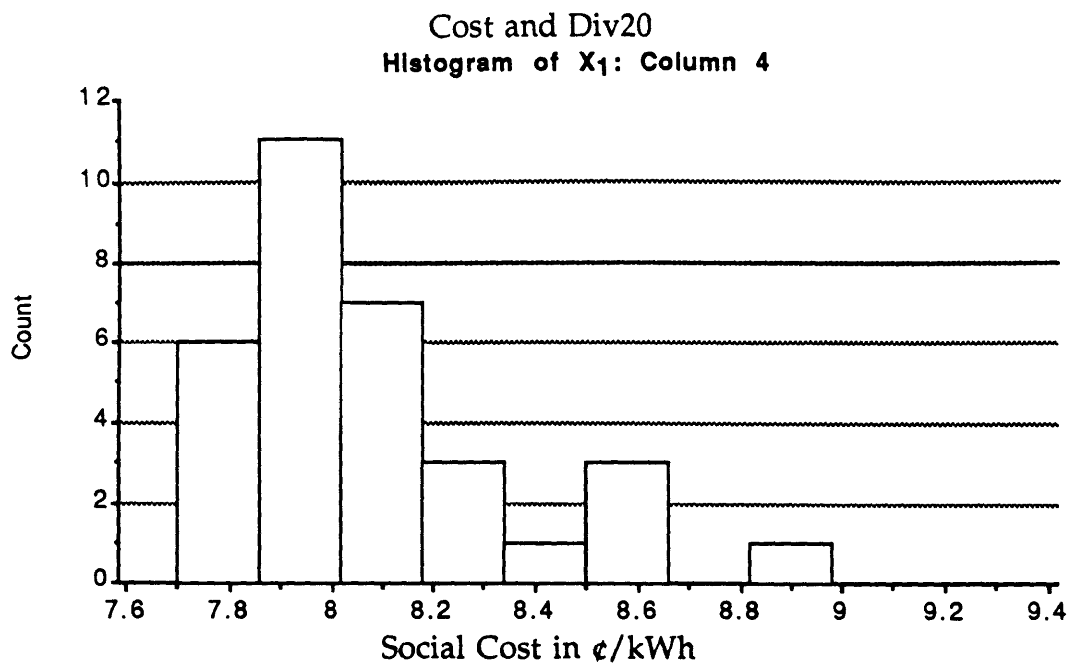


Figure 6

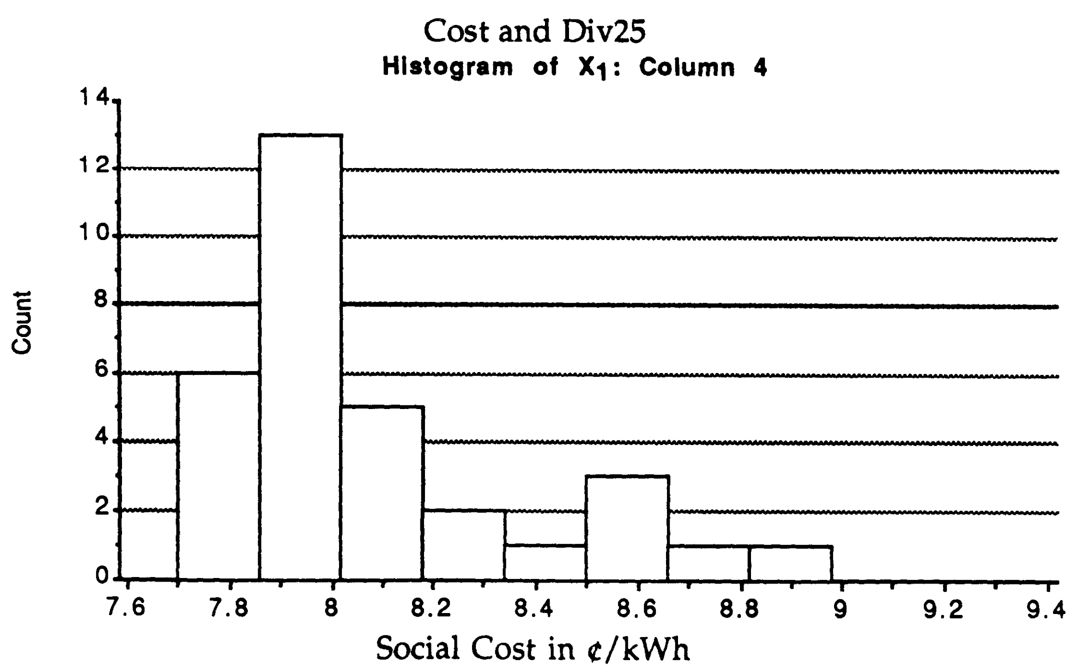


Figure 7

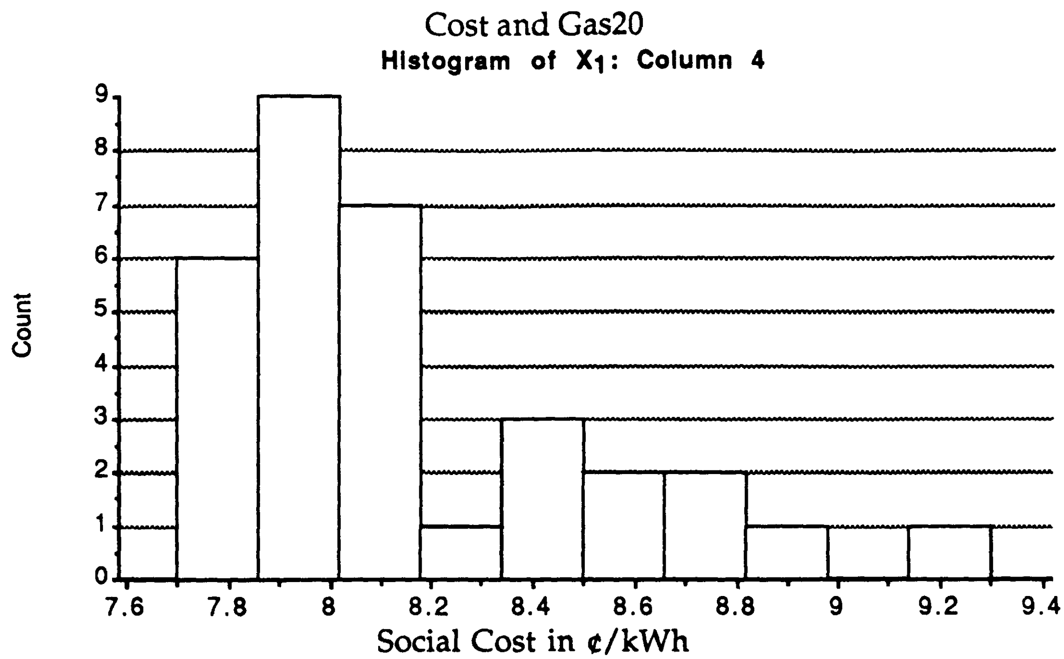


Figure 8

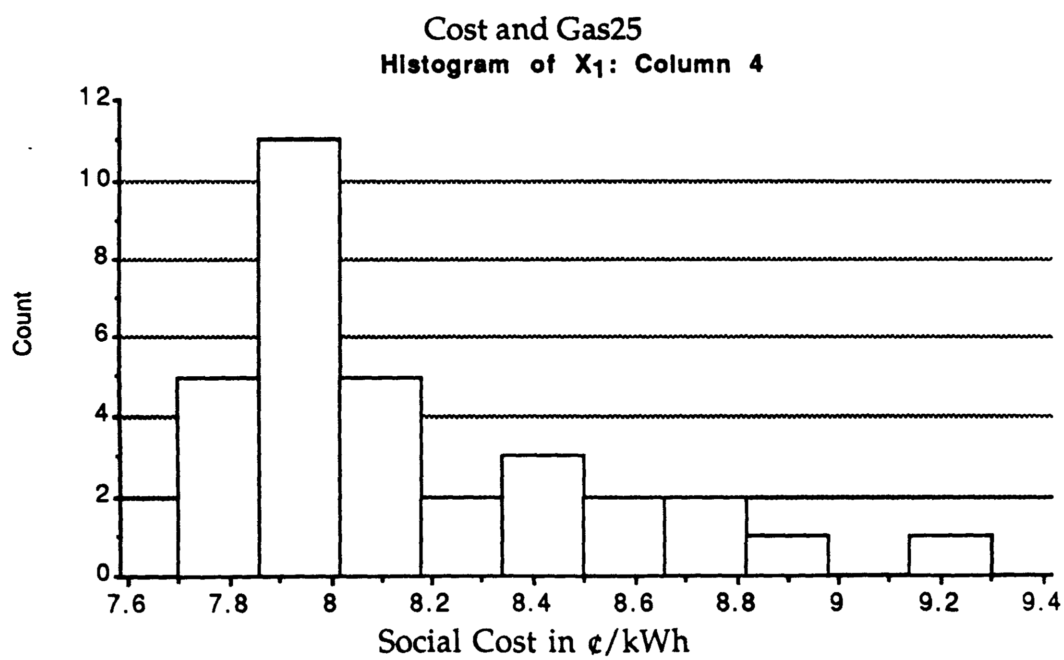


Figure 9

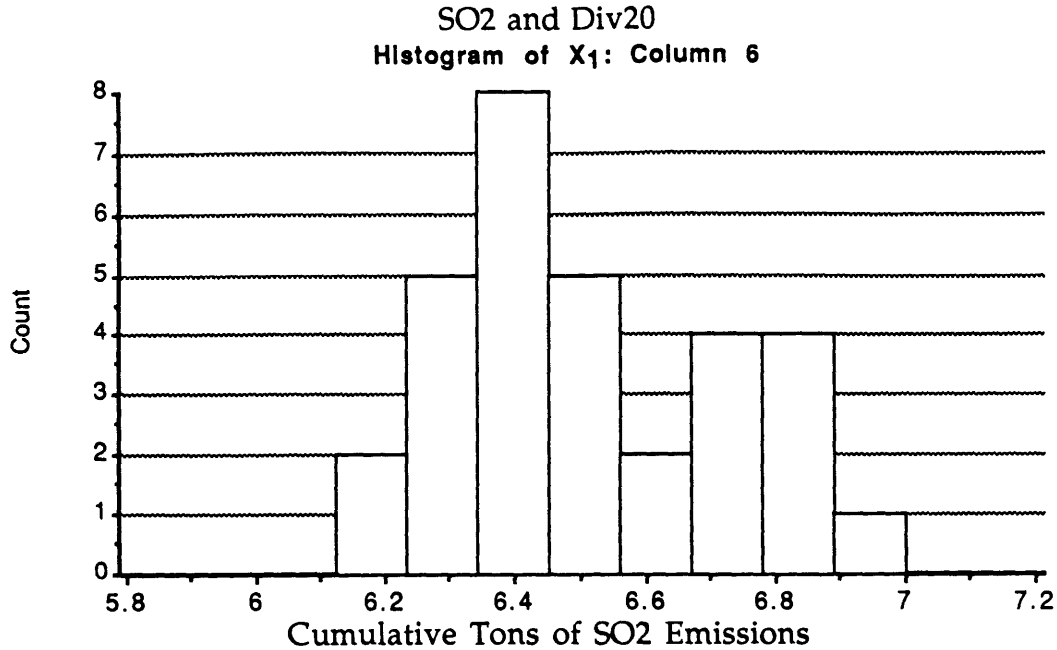


Figure 10

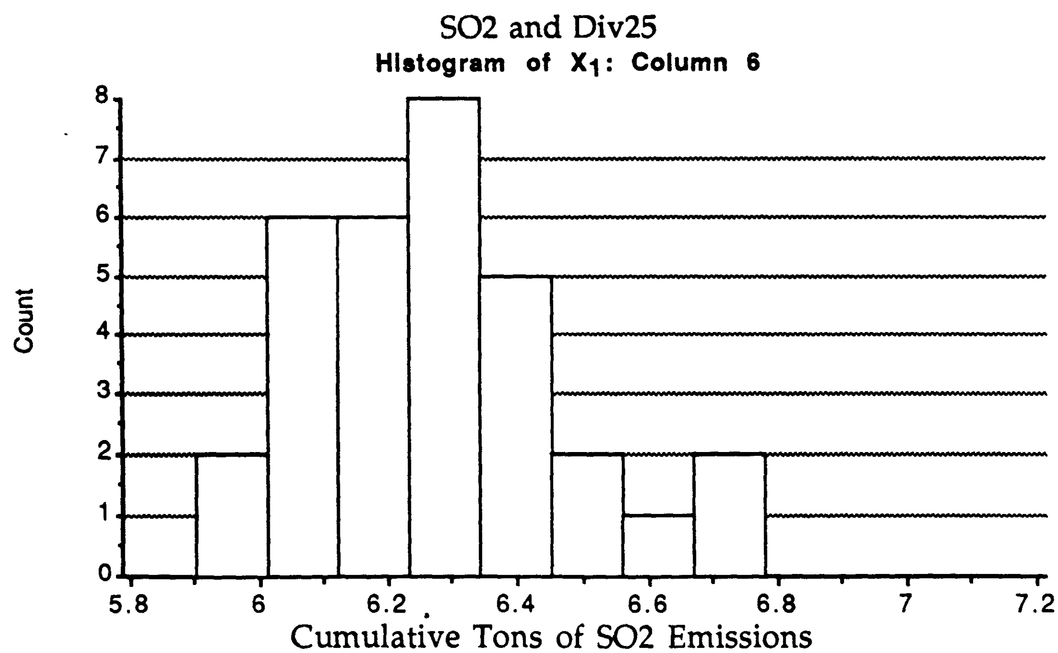


Figure 11

SO2 and Gas20

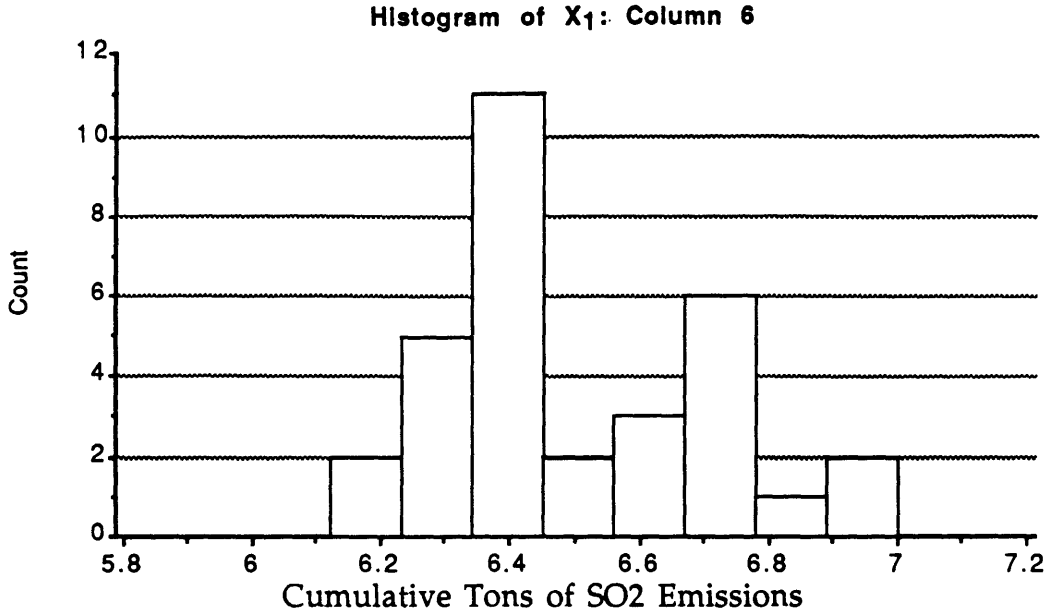
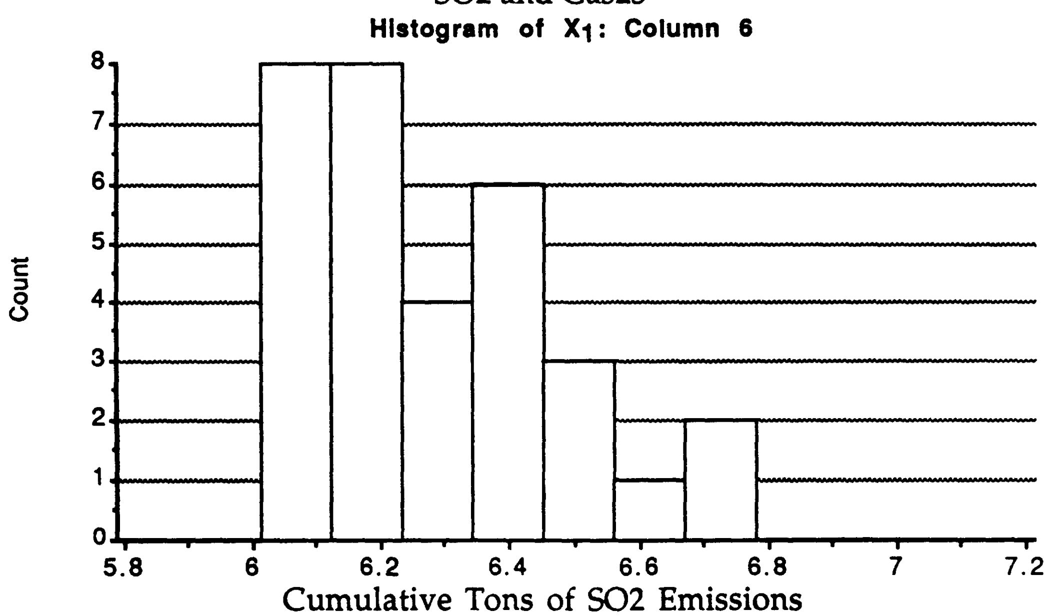


Figure 12

SO2 and Gas25



Figures 13-16, the histograms for the strategy specific attribute variation for cumulative level 5 danger hours, show a strong shift to the left as the reserve margin is increased from 20 to 25%. Although the dispersion remains about the same, the means are halved. The shape of the distribution changes substantially from the global case, with the exception of the Div20 strategy, moving from something roughly uniform to a clear bimodal shape. It is interesting to note that the strategies incorporating the gas dependent option perform marginally better than those with the diversified (as measured by mean, maximum, and standard deviation; not by minimum, however); this is probably due to the "window of vulnerability" caused by the significantly longer lead time required to add coal plants.

Figure 13

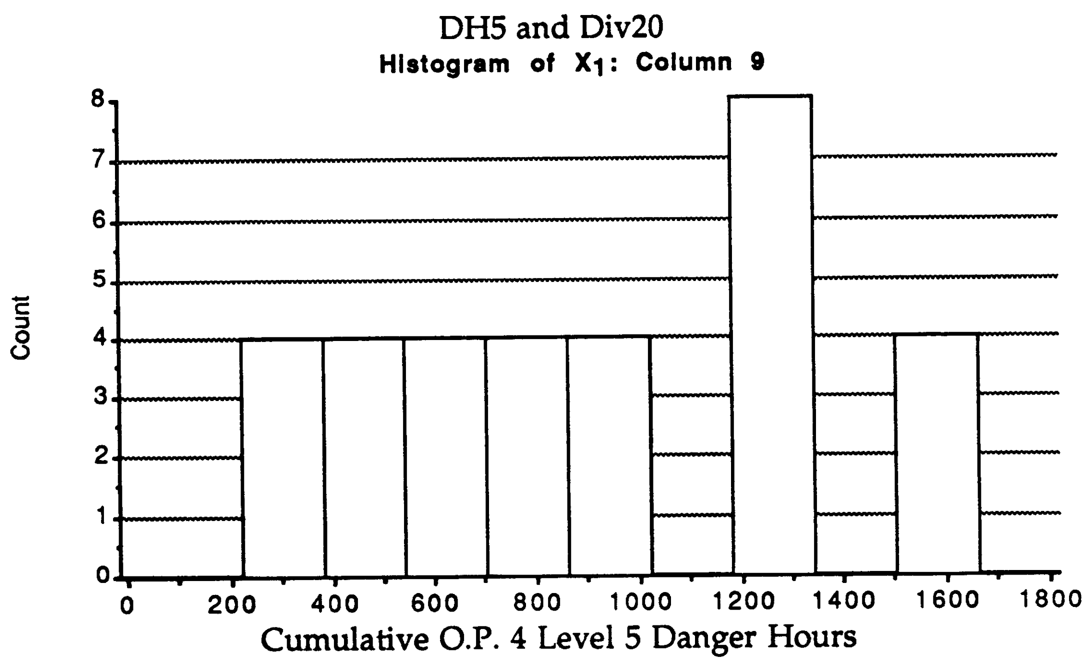
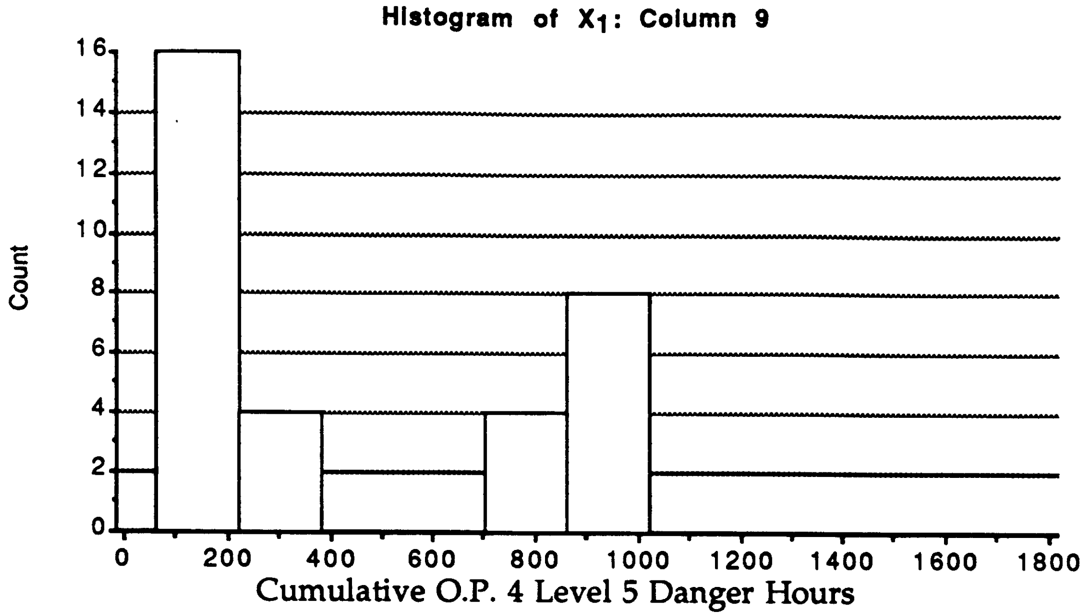


Figure 14

DH5 and Div25



Reviewing the analysis of strategy specific attribute variation (in response to question 4 in Section 6), there is some indication that gas dependent strategies are more variable (with potentially better and worse outcomes) than diversified cases with respect to cost and that larger reserve margins are associated with lower SO2 emissions and Level 5 danger hours, but potentially higher costs. It would be foolhardy (or a sign of somebody with a fixed agenda and pre-selected answer) to make a decision or to pursue discussions about choices based solely on these results. But now that the nature of the possible trade offs has been indicated, the participant can move forward to explore the extent of the required trade offs, taking into consideration the likelihood of the futures and the importance of the attributes.

Figure 15

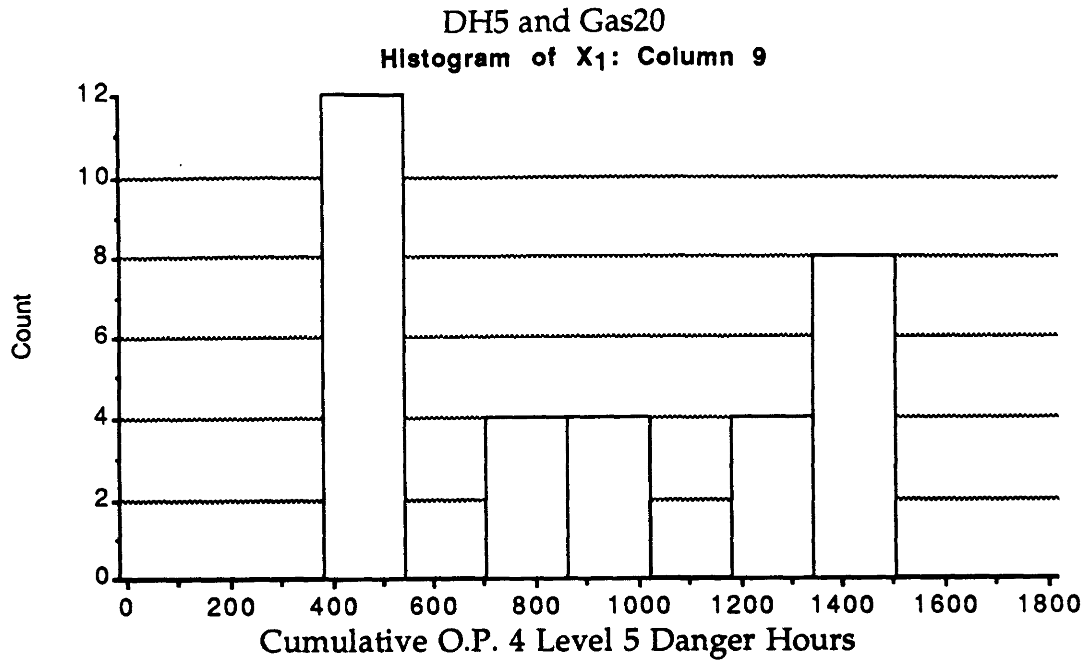
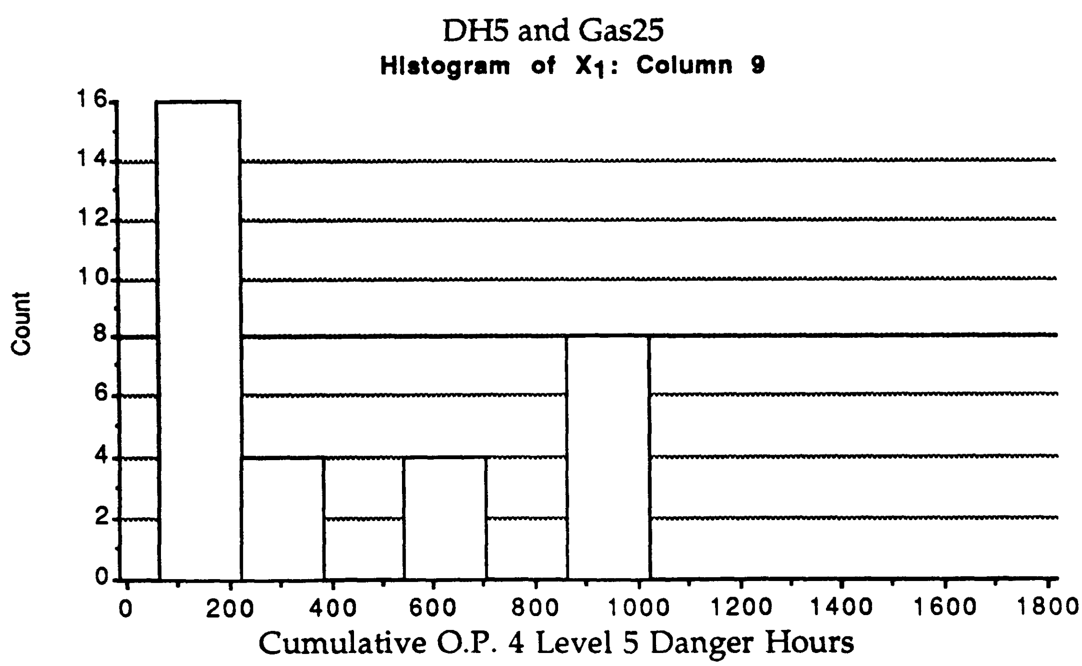


Figure 16



Section 7 Robustness

The next block of the trade off framework is the robustness stage. This stage involves the identification and possible elimination of highly variable, "non-robust" solutions. An important caveat is in order here. The development of this section resulted from theoretical work and it is not clear how often this problem occurs in real applications. In general, it is not recommended that the participant eliminate non-robust strategies until a careful and iterative analysis is done, and perhaps not even then. One might view this stage as having two purposes: 1) requiring the participant to carefully examine the variability of the strategies[1] and 2) justifying the necessity of the juxtaposition of two sorting techniques in the next stage.

The second purpose is important because the inclusion of non-robust strategies in later stages of the analysis can mask the existence of other, potentially better, strategies (but only in the cases where dominance is applied as a screen via the efficient sets approach). Therefore, this is only a problem when the number of strategies is large enough to require that dominance be utilized to select an efficient set for the ensuing trade off analysis or whenever a method, such as EPRI's RISKMIN software, is utilized that is based solely on the selection of efficient sets using dominance.

[1]This is in and of itself an important outcome. As discussed earlier, the selection of robust strategies is an important goal of the IRP process. Achieving this requires that the participant consider the variability of the strategies. This stage is an appropriate time for this examination.

The following example demonstrates why this step is theoretically necessary[1] when dominance concepts are applied to determine the efficient sets. Five utility planning strategies (A, B, C, D, E) are being considered with respect to four criteria - cost, reliability, SO2 emissions, and dependence on foreign oil - all of which are preferred at lower levels, all else equal. There are two futures. Table 5 summarizes the decision matrix available to the decision maker.

Table 5

Example of Dominance Eliminating a "Robust" Alternative

	Future 1				Future 2			
Plan	Cost	DH5	SO2	Dep.	Cost	DH5	SO2	Dep.
A	1	5	3	2	1	5	3	2
B	5	1	1	3	5	1	2	3
C	3	3	3	3	3	3	3	3
D	2	1	3	2	5	5	2	3
E	5	5	2	3	2	1	3	2

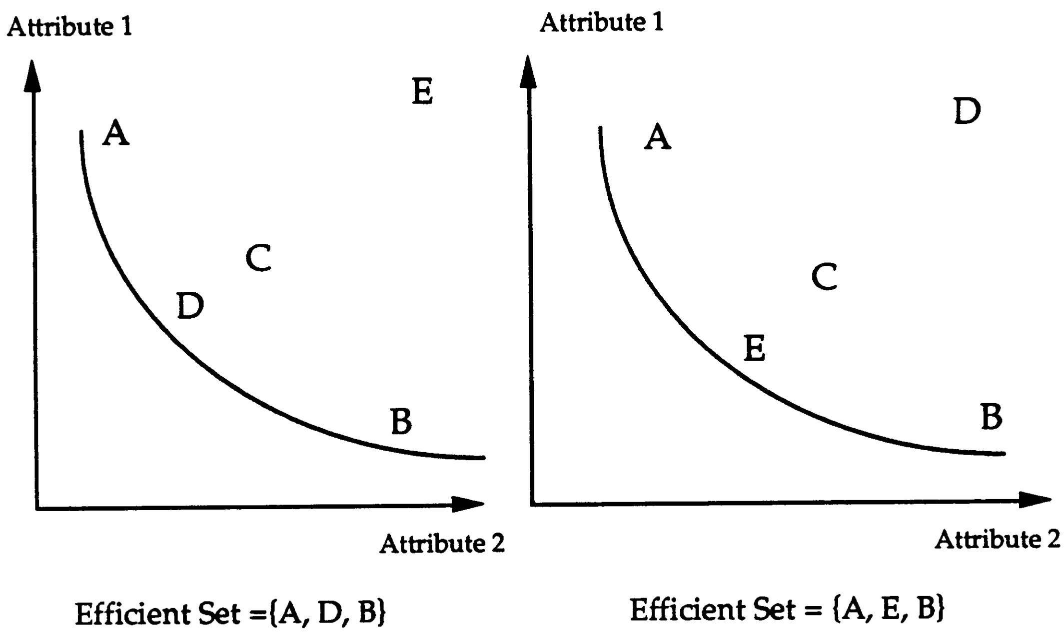
The efficient set for future 1 is {A,B,D} and the efficient set for future 2 is {A,B,E}. RISKMIN and other techniques that rely significantly on the use of dominance to eliminate "poor" strategies would fail to further consider plan C in this case - a strategy that might be chosen by many participants as the most desirable because of its inherent robustness. This occurs because C is

[1] I apologize for the simplicity of the example. It is only intended to provide some theoretical basis for the importance of this stage. The data from the AGREA study example does not contain an appropriate example of such a problem at any level, probably due in part to the limited number of strategies analyzed.

dominated in turn by D and E, which are both extremely sensitive to the uncertainties modeled in futures 1 and 2. See Figure 17 for a two attribute, two future example.

Figure 17

Example of Non-Robust Strategies Masking a Robust Strategy



The importance of C as a robust option is predicated on the assumption that D and E are less preferred because of their variability - in other words, that they are less robust. Note that non-robustness (and therefore robustness also, of course) is a subjective notion, which depends on the preferences and beliefs of the decision maker.

Section 7.1 Identification of Non-robust Strategies

The purpose of the procedures outlined in this section is to allow the user to identify non-robust solutions.[1] Because robustness is a subjective notion, the methods discussed in this section require the user's judgement (as do most of the stages in MATOF). Two measures are presented - 1) a maximum/minimum numeraire and 2) a standard deviation matrix. One or the other (or both) could be used, depending on the preferences of the participant. They both have their advantages and disadvantages and are best used in conjunction with the results of the attribute variability analysis. The max/min numeraire is more appropriate when the magnitudes of the possible poor outcomes are most important, while the standard deviation matrix is best used when variability, regardless of the magnitude of the attributes, is a concern.

The max/min numeraire, ${}_AV_i$, is defined to be the maximum value (over all futures) of attribute A for strategy i minus the minimum value of that attribute. To indicate the variability of a strategy, a max/min vector can be constructed, so that:

$$\mathbf{V_i} = ({}_1V_i , \ldots\ldots\ldots, {}_NV_i) \quad \text{for attributes } 1,\ldots,N$$

This measure has two obvious drawbacks. First, it is not clear how to incorporate probabilities for futures into this measure. One possibility would be to look at the implied pdf for the attribute and arbitrarily take the 90th and

[1] Since a robust strategy is defined to be one which performs well for a wide variety of different futures, the terms non-robust and highly variable are being used with similar meanings in this paper. Other undesirable traits of strategies could also be defined and analyzed within the framework..

10th percentile values as the maximum and minimum, respectively. The second problem is that such a measure does not account for the distribution of the values. The advantage is that it allows the participant to focus on the comparison between the best and worst possible outcomes in the units of the attribute (hopefully defined so that changes in an attribute value have a clear meaning to the participant).

The analysis procedure is as follows. The set of max/min vectors are "stacked" to create a max/min matrix with the addition of the global max/min value as the first row to facilitate comparisons. The participant would select non-robust solutions, if any exist, by comparing the global max/min value with those for the individual strategies to determine if any strategy appears to have an unacceptable spread for a large number of the attributes.

The standard deviation measure addresses some of the disadvantages of the max/min numeraire since it can be defined to include the probabilities of the futures and it is a better measure of the entire dispersion of the underlying pdf of the variable. A standard deviation matrix can be developed by calculating the value for each strategy and attribute across all uncertainties.

In conjunction with the data and trade off analysis performed earlier, the standard deviation matrix can be used (in much the same fashion as the max/min matrix) to judge which plans have an "unacceptable" (defined in this case as excessively variable) performance measured across all the futures and attributes. These plans are then eliminated from the decision matrix and not considered further. Having said this, it is important to re-iterate that the elimination of feasible strategies should in general be avoided before the trade off analysis stage, in order to prevent unintentional circumvention of the consensus building goal of IRP (i.e. the participants should come face-to-face with the trade offs of the strategies favored by others).

Section 7.2 Example of Non-robust Strategy Identification

In general, as discussed at the beginning of Section 7.1, it is neither appropriate nor desirable to apply this procedure to an analysis with a limited number of strategies. With that caveat, the results of the AGREA study are presented to demonstrate how the max/min and standard deviation matrices would be formulated and analyzed.

Table ..6

Example of Robustness Measures

Max-Min

Attributes

	Society's Leviz Cost (¢/kWh)	% Total MCF Forced Fuel Switching	Cumulative SO2 Emissions (MM Tons)	Cumulative NOx Emissions (MM Tons)	Cumulative SP Emissions (MM Tons)	Cum. OP 4 Activity Level 5 Danger Hrs
Global	1.55	49.3	1.08	1.08	0.53	1575
Gas20	1.53	48.3	0.75	1.00	0.45	939
Gas25	1.54	49.3	0.74	0.99	0.48	858
Div20	1.05	39.5	0.87	0.99	0.32	1300
Div25	1.16	43.9	0.85	0.99	0.32	930

Standard Deviation

Attributes

	Society's Leviz Cost (¢/kWh)	% Total MCF Forced Fuel Switching	Cumulative SO2 Emissions (MM Tons)	Cumulative NOx Emissions (MM Tons)	Cumulative SP Emissions (MM Tons)	Cum. OP 4 Activity Level 5 Danger Hrs
Global	0.33	13.5	0.24	0.31	0.11	452
Gas20	0.37	14.7	0.20	0.32	0.11	380
Gas25	0.38	15.1	0.21	0.31	0.12	350
Div20	0.28	11.3	0.23	0.32	0.10	437
Div25	0.30	12.6	0.21	0.31	0.10	395

Table 6 includes both the standard deviation and max/min matrices. In my opinion none of the four strategies exhibits "unacceptable" variation across a large number of the attributes, particularly when the global variability is used as a comparison measure. The global max/min result is a useful benchmark - if a strategy has a similar value then that strategy must span the range of all possible outcomes for that attribute. The results in Table 6 support the earlier conclusions that natural gas dependent strategies are more variable with respect to cost. In addition, Level 5 danger hours has a large dispersion for the diversified 20% strategy.

Section 8 Sorting and Efficient Set Generation

After the completion of the robustness stage, the participant should move on to analyze the performance of the strategies in a general manner, after which trade off analysis will be done. There are two somewhat parallel techniques described in this section - sorting and efficient set generation. Since both these techniques are aimed at helping to focus the participant's attention on the better performing strategies and their trade offs (moving a step beyond the a priori identified preferences), they are not necessarily required in tandem. Clearly, however, if dominance is going to be used to select a smaller subset of an unmanageably large number of strategies, then by definition efficient set generation techniques must be used.

Section 8.1 Efficient Set Generation

Once the final set of feasible and robust strategies has been selected, it can be useful to determine the global and local efficient sets by applying either strict or significant dominance. It is important to realize that this step is conceptually very different from the elimination of non-robust strategies undertaken in the previous stage. In that procedure strategies that may have been in at least one local efficient set (and therefore in the global set) are eliminated because of their high variability. In the dominance step, strategies are screened out because of their poor attribute performance, relative to another plan. A major disadvantage of this technique is its lack of discriminatory power. With a wide range of futures, it is quite likely that almost every plan will be in at least one local efficient set and therefore in the global efficient set. However, the tabulation of the results, as described below, presents the participant with information about the relative robustness of all the strategies.

The efficient set for each of the futures (i.e. all the local sets) can be listed (if desired and if the number is not overwhelming) and the plans in the global set can be tabulated, along with the number of futures (or the cumulative probability) supporting it. In addition, displayed with each plan included in the global set should be the futures which do not include it in their local efficient set.

Section 8.2 Example: Efficient Set Generation

Tables 7 and 8 present the results from the efficient set generation procedure, assuming strict dominance is applied[1]. It is striking to consider the limited number of times that Gas20 is a dominant strategy (and thus represented in a local efficient set) when compared to the performance of the other three strategies.

Table 7

Tabulation of Efficient Set Membership

	No. of Times in Local Efficient Set
Gas and 20%	8
Gas and 25%	27
Div and 20%	22
Div and 25%	30

Note that 32 (the number of futures) is the maximum possible value

The futures for which Gas20 is in the local efficient set can be found in Table 8. A no response indicates that the strategy is not dominated and therefore in the efficient set. Somewhat surprisingly, only three of the cases occurred in a future with the Additions case for gas availability. Six of the cases resulted in futures when a fuel act was passed.

The futures that do not support Div25 (only 2) are futures 28 and 32; both with H/U fuel prices, aggressive demand side management (DSM2), and a fuel act. All of these belong to the the group of uncertainty values that I

[1] Some of the results may not correspond exactly with the reader's attempts to replicate this chart using the data from the decision matrix. This is due to rounding - most of the numbers that appear exactly the same to two digits are different, which is picked up by the application of strict dominance.

Table 8

Scenario		Dominated
Future	Strategy	Strategy?
1	Gas and 20%	yes
Base M/C NA	Gas and 25%	yes
CELT	Div and 20%	no
	Div and 25%	no
2	Gas and 20%	yes
Base M/C NA	Gas and 25%	no
BB	Div and 20%	no
	Div and 25%	no
3	Gas and 20%	yes
Base M/C NA	Gas and 25%	yes
DSM1	Div and 20%	no
	Div and 25%	no
4	Gas and 20%	yes
Base M/C NA	Gas and 25%	no
DSM2	Div and 20%	no
	Div and 25%	no
5	Gas and 20%	no
Add M/C NA	Gas and 25%	no
CELT	Div and 20%	no
	Div and 25%	no
6	Gas and 20%	yes
Add M/C NA	Gas and 25%	no
BB	Div and 20%	no
	Div and 25%	no
7	Gas and 20%	no
Add M/C NA	Gas and 25%	no
DSM1	Div and 20%	yes
	Div and 25%	no
8	Gas and 20%	yes
Add M/C NA	Gas and 25%	no
DSM2	Div and 20%	no
	Div and 25%	no
9	Gas and 20%	yes
Base H/U NA	Gas and 25%	yes
CELT	Div and 20%	no
	Div and 25%	no
10	Gas and 20%	yes
Base H/U NA	Gas and 25%	no
BB	Div and 20%	no
	Div and 25%	no
11	Gas and 20%	yes
Base H/U NA	Gas and 25%	yes
DSM1	Div and 20%	no
	Div and 25%	no
12	Gas and 20%	yes
Base H/U NA	Gas and 25%	no
DSM2	Div and 20%	no
	Div and 25%	no
13	Gas and 20%	yes
Add H/U NA	Gas and 25%	no
CELT	Div and 20%	yes
	Div and 25%	no
14	Gas and 20%	yes
Add H/U NA	Gas and 25%	no
BB	Div and 20%	no
	Div and 25%	no
15	Gas and 20%	yes
Add H/U NA	Gas and 25%	yes
DSM1	Div and 20%	yes
	Div and 25%	no
16	Gas and 20%	yes
Add H/U NA	Gas and 25%	no
DSM2	Div and 20%	no
	Div and 25%	no

Scenario		Dominated
Future	Strategy	Strategy?
17	Gas and 20%	no
Base M/C FA	Gas and 25%	no
CELT	Div and 20%	no
	Div and 25%	no
18	Gas and 20%	yes
Base M/C FA	Gas and 25%	no
BB	Div and 20%	no
	Div and 25%	no
19	Gas and 20%	no
Base M/C FA	Gas and 25%	no
DSM1	Div and 20%	no
	Div and 25%	no
20	Gas and 20%	no
Base M/C FA	Gas and 25%	no
DSM2	Div and 20%	no
	Div and 25%	no
21	Gas and 20%	yes
Add M/C FA	Gas and 25%	no
CELT	Div and 20%	yes
	Div and 25%	no
22	Gas and 20%	yes
Add M/C FA	Gas and 25%	no
BB	Div and 20%	no
	Div and 25%	no
23	Gas and 20%	no
Add M/C FA	Gas and 25%	no
DSM1	Div and 20%	no
	Div and 25%	no
24	Gas and 20%	yes
Add M/C FA	Gas and 25%	no
DSM2	Div and 20%	yes
	Div and 25%	no
25	Gas and 20%	no
Base H/U FA	Gas and 25%	no
CELT	Div and 20%	no
	Div and 25%	no
26	Gas and 20%	no
Base H/U FA	Gas and 25%	no
BB	Div and 20%	no
	Div and 25%	no
27	Gas and 20%	yes
Base H/U FA	Gas and 25%	no
DSM1	Div and 20%	yes
	Div and 25%	no
28	Gas and 20%	yes
Base H/U FA	Gas and 25%	no
DSM2	Div and 20%	yes
	Div and 25%	yes
29	Gas and 20%	yes
Add H/U FA	Gas and 25%	no
CELT	Div and 20%	yes
	Div and 25%	no
30	Gas and 20%	yes
Add H/U FA	Gas and 25%	no
BB	Div and 20%	no
	Div and 25%	no
31	Gas and 20%	yes
Add H/U FA	Gas and 25%	no
DSM1	Div and 20%	yes
	Div and 25%	no
32	Gas and 20%	yes
Add H/U FA	Gas and 25%	no
DSM2	Div and 20%	yes
	Div and 25%	yes

originally classified as less likely. Gas25 is also in a large number of efficient sets; it is interesting to note, however, that the five futures that do <u>not</u> support it all include the more likely no fuel act case.

As expected, the efficient set generation procedure proved unable to eliminate any strategies. However, it indicates that certain of the strategies - notably Gas25 and Div25 - are particularly robust. If the participant is interested in exploring the strategies further at a preliminary level, Sorting (Section 8.3) allows the decision maker input in defining good and poor performances. The analysis to this point is important in framing the problem, but it is not yet sufficient to argue for a particular strategy. Although Div25 appears to be very robust, we have only sketchy data about the trade offs required by that choice. In other words, robustness is only one of the possible selection criteria - we must have information on the trade offs across the other attributes before making a decision.

Section 8.3 Sorting

The previous stages show the decision maker the ranges of the attributes that must be considered in the trade off and selection process and possibly eliminates those that are particularly non-robust. Sorting depends on the attribute variability stage for assistance in selecting a reasonable set of criteria.[1] Once these attribute screening levels are chosen, the sorting stage helps the participant to identify "good" and "poor" strategies by means of two conjunctive sorts that select only those strategies that perform either

[1] There is one case in which the attribute variation analysis is not essential to this stage. If the participant has pre-specified completely inflexible critical levels for all the attributes, the sorting could be done with these values. However, this variability analysis will be sorely missed should this person attempt the trade off analysis with an open mind.

particularly poorly or well for all attributes in a given future. Such methods do not consider possible compensatory trade offs (i.e. a poor performance for only a single attribute cannot be compensated for by outstanding results for all of the remaining attributes), and thus represent only an additional way of gaining insight into the data before moving on to the formal trade off analysis.

After the participant has become familiarized with the data and considered in more detail what attribute levels are "critical", an initial sort of the plans can be made. Two conjunctive sorting procedures are suggested here, one aimed at screening out all those strategies that perform well across all the attributes, the second aimed at finding those that perform poorly.

Conceptually, the procedure is simple. Critical attribute values (either high or low) are selected as thresholds. Then for each future, the plans that exceed this level are selected. The results can be tabulated in a number of ways. Three possibilities are suggested here. First, plans that are selected in every future should be highlighted. Second, the number of times each plan is selected (in the non-uniform probabilities case, the sum of the probabilities for the futures in which they are selected could be used) should be presented. Third, contingent on the number of futures, one could list each future and the strategies selected.

The results presented in this type of tabulation are similar in nature to the efficient set results. However, the procedures do have some distinct differences. The generation of efficient sets informs the participant about the number of times that a strategy is not dominated, but without reference to the magnitude of the attribute values (i.e. it requires no judgement or information from the participant). The sorting procedure identifies those strategies (and the futures in which they occur) that exceed or fail a screening of user-provided critical levels. This supplies the participant with information and feedback that is relevant to their own personal preferences and beliefs.

Despite the simplicity of the approach, the decision maker might be unable or unwilling to specify critical attribute values. In this case, it would be appropriate to use some attribute value in the lower or upper quartile, respectively. A variation on the technique would be to scale the data using a percent scale transformation (in which the best value always receives a 1, the worst a 0, and the intermediate values are calculated as the percentage of their deviation from the best with respect to the total difference from best to worst). Such a procedure would highlight the differences between results even for attributes with little variability, and therefore increases the power of the sort to distinguish between strategies. This approach must be used with caution because of the dramatic change in the relative relationship between the attribute values when percent scale transformations are used, and therefore it is not recommended for most applications.

The goal of this stage is to do a preliminary analysis to determine strategies that appear particularly attractive to the decision maker. If the participant has no a priori selection of strategies to focus on in the next step of trade off analysis, sorting will help to select a subset. It will also indicate, assuming that a large set of plans have been modeled, whether only a smaller subset of these warrant detailed analysis, although one must always be careful in discarding plans based solely sorting.

Section 8.4 Example: Sorting

To perform the sorting technique one first must select a set of screening values for the attributes. For the first case, I will take the same set of critical levels for the sort screening for good strategies and for that searching for poorly performing ones. I will use the critical levels defined in the a priori information elicitation stage for cost, SO2 and Level 5 danger hours and the global average for the remaining three attributes. In the second case, I will define stricter screening criteria for both the good and poor sort.

Table 9 illustrates the results of the first case.

Table 9

Attribute Values Used as Screening Criteria

Societal Cost (¢/kWh)	Forced Fuel Switching (Percent)	SO2 Emissions (MM tons)	NOx Emissions (MM tons)	SP Emissions (MM tons)	Level 5 Danger Hours (Cumul. hrs)
8.26	9.8	6.40	3.38	5.10	500

No. of Futures Selected

	Good	Poor
Gas and 20%	2	6
Gas and 25%	9	6
Div and 20%	4	5
Div and 25%	9	2

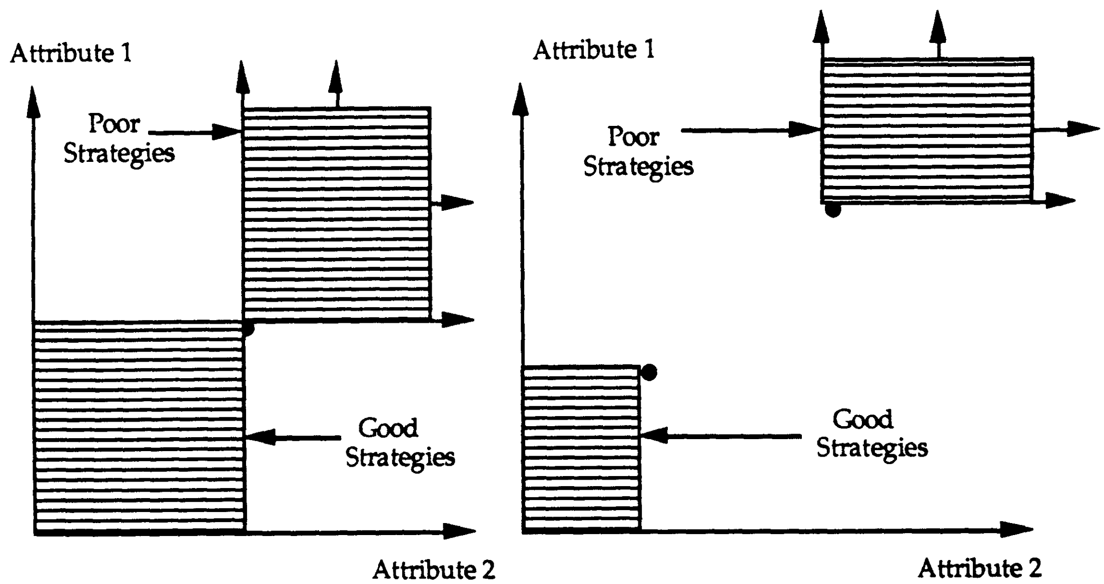
It is interesting to note that all of the poor cases occur in futures with the boom-bust load growth trajectory and that none of the good cases existed for such futures. This suggests that higher electricity demand is associated with larger (and hence less desirable) attribute values and that all else being equal we prefer less load growth. Such a conclusion may be misleading because of the absence of attributes such as employment or state tax revenues that may be positively correlated with demand growth. This might also be an indication that demand side management efforts should be vigorously pursued. That may be so; however, this study assumed no cost for the DSM programs implied in the lower demand growth cases.

The second case utilizes stricter criteria for screening out both the poor and the good cases. This example is presented in Table 10. The difference between these two approaches to sorting is illustrated in Figure 18, for a two attribute case. The graph on the left is the case in which a single screen is used to choose both good and poor strategies, the one on the right uses two more restrictive screens to perform the screening.

This set of screenings suggests several things. First, that there are not many combinations of strategies and futures that perform very well (or very poorly) for all of the attribute values. This means that the final choice will be a difficult one and require making the challenging trade offs that were suspected from the beginning. It does suggest, however, that the trade off analysis should be focused on the choice between the diversified and gas dependent options for a 25% planning margin.

Figure 18

Examples of Two Types of Sorting Screens
(Assumption: smaller attribute values are better)



Based on these results, my recommendation would be to begin the trade off analysis with a consideration of the choice between the possible reserve margins - focusing carefully on the cost trade offs implied by the increase. If those should prove acceptable, one could move on to comparing gas dependent versus diversified[1]. In general, one cannot expect the results to be as benevolent as these - it turns out that this is a good way to approach the problem because, with the exception of cost and forced fuel switching, the 25% option dominates the 20% one for the other four attributes across all of the

[1] Note that it is only possible to do this pairwise comparison because all possible combinations of 2 sets of very distinct and broad options were used to create the strategy set. If this were not the case (for instance assume the strategies were simply labeled A,B,C and D, respectively), the approach would have to be to focus on B and D (in the examples in Tables 9 and 10 above) and trying to understand what trade offs they require over A and B (assuming they do not dominate them).

Table 10

Attribute Values Used as Screening Criteria

Societal Cost (¢/kWh)	Forced Fuel Switching (Percent)	SO2 Emissions (MM tons)	NOx Emissions (MM tons)	SP Emissions (MM tons)	Level 5 Danger Hours (Cumul. hrs)
The "Good" Screen					
8.00	5.0	6.25	3.10	5.00	400
The "Poor" Screen					
8.40	20	6.70	3.60	5.20	750

No. of Futures Selected

	Good	Poor
Gas and 20%	0	4
Gas and 25%	2	0
Div and 20%	1	2
Div and 25%	3	1

futures. If the strategies are not as easily distinguished as in this study (see footnote), the approach from this point would be to consider the trade offs between the a priori preferred strategy and any identified through the sorting and efficient set generation procedure, trying to understand what, if anything, gives them an advantage and what trade offs this implies for other participants.

One last point on the difference between sorting and efficient set generation. It is entirely possible that the two methods could have different results (although not the case here) because the efficient set generation technique (particularly in the case of strict dominance) effectively weights all of the attributes evenly, while the sorting technique relies on user input that is not constrained in this fashion.

Section 9 Irrelevant Uncertainties

The process of identifying irrelevant uncertainties depends entirely on the chosen definition of an irrelevant uncertainty. Let us define an irrelevant uncertainty as one which does not change the relative position of the strategies in the attribute space, for all the possible combinations of the remaining uncertainties. The relative position of the strategies can be most simply defined by their rank order.

This definition suggests the following procedure:

1) Determine the rankings of the plans for each attribute within each future

2) Create subsets of futures. Each subset should include all futures that have only one combination of the uncertainties <u>not</u> being examined and all possible variations of the one under analysis

3) If the rankings of the strategies change for any attribute in any of these subsets, then the uncertainty is not irrelevant

Table 11 demonstrates this procedure for a case with 2 uncertainties (each capable of assuming two outcomes- i.e., p1,p2,u1,u2), 2 strategies (a1,a2), and 3 attributes.

Table 11

Irrelevant Uncertainties Example

Future	Strategy	Attributes: Att1	Att2	Att3
u1p1	a1	3	1	2
	a2	1	3	1
u1p2	a1	2	2	2
	a2	1	3	1
u2p1	a1	2	3	4
	a2	3	1	6
u2p2	a1	1	5	1
	a2	3	4	5

The subsets for analyzing uncertainty u are: {u1p1, u2p1} and {u1p2, u2,p2}. The correct subsets for analyzing the irrelevancy of p are {u1p1, u1p2} and {u2p1, u2p2}.

The Irrelevancy of Uncertainty U

Future	Strategy		Attributes: Att1	Att2	Att3
u1p1	a1 \		3	1	2
	a2 \		1	3	1
		Subset 1 for U			
u2p1	a1 /		2	3	4
	a2 /		3	1	6
u1p2	a1 \		2	2	2
	a2 \		1	3	1
		Subset 2 for U			
u2p2	a1 /		1	5	1
	a2 /		3	4	5

The Irrelevancy of Uncertainty P

Future	Strategy		Attributes: Att1	Att2	Att3
u1p1	a1 \		3	1	2
	a2 \		1	3	1
		Subset 1 for P			
u1p2	a1 /		2	2	2
	a2 /		1	3	1
u2p1	a1 \		2	3	4
	a2 \		3	1	6
		Subset 2 for P			
u2p2	a1 /		1	5	1
	a2 /		3	4	5

Assuming that all of the attributes are to be minimized, we see that U is definitely relevant (the rankings of the two strategies switch in both subsets and for all the uncertainties) while P satisfies the definition of an irrelevant uncertainty.

Operationally, this implies that the specific value of P has no impact on the rankings of the strategies in the attribute space. (The fact that P is "irrelevant" does not imply that it has no effect on the levels of the attributes, however). This procedure has the drawback of all ordinal measures - the magnitudes of the trade offs can change substantially within the same rank structure. For example, attribute 3 in subset 2 for uncertainty P demonstrates this clearly. This suggests that a cardinal measure, such as absolute deviation or the percentage change between plans, might be more appropriate. The problem here is one of implementation. If one utilizes the sign of the measure this becomes equivalent to the ordinal procedure. If the additional information in the cardinal measure is to be included, tolerance levels must be defined by the user. Since this is essentially what trade off analysis seeks to accomplish, the use of a cardinal measure to analyze the relevancy of uncertainties is not feasible.

The RISKMIN program defines an irrelevant uncertainty as one which has no effect on the plans in the global efficient set. Although this is similar in nature and intent to the procedure outlined in this section, it does not utilize the more specific information that is available. Examples include: 1) Are there any attributes for which relevant uncertainties are actually irrelevant?, and 2) Are there any strategies that appear to switch ranks more frequently?

If probabilities have been assessed for the futures, the procedure can be modified to include them. Two simple possibilities suggest themselves. First, any rank switching in futures with probabilities lower than a small threshold value p could be disregarded. If there were many such scenarios, however, the cumulative probability of a rank change could become relatively large. Therefore, the second approach addresses this problem by aiming the threshold at the cumulative likelihood of a rank change.

Section 9.1 Example: Irrelevant Uncertainty

The results of the irrelevant uncertainty analysis is presented in Table 12. The appropriate subsets were created for each of the four uncertainties considered in the AGREA study. The ordinal ranking of the strategies for each future in these subsets[1] was determined for all of the six attributes. Then the rankings were compared across all of the futures in the subset. If no

[1] There were sixteen subsets for each of the uncertainty sets with two possible outcomes and eight for the load growth uncertainty, which had four possible outcomes.

Table 12

Summary of Irrelevant Uncertainty Analysis for AGREA Study

Base/Additions.	Cost	FFS	SO2	NOx	SP	DH5
Number of Times Irrelevant for Attribute:	8	3	14	10	13	16
Number of Times Irrelevant for Sets of Attributes:				3		

Fuel Prices	Cost	FFS	SO2	NOx	SP	DH5
Number of Times Irrelevant for Attribute:	3	14	14	10	13	16
Number of Times Irrelevant for Sets of Attributes:				2		

Load Growth	Cost	FFS	SO2	NOx	SP	DH5
Number of Times Irrelevant for Attribute:	0	2	0	0	1	0
Number of Times Irrelevant for Sets of Attributes:				0		

No Act/Fuel Act	Cost	FFS	SO2	NOx	SP	DH5
Number of Times Irrelevant for Attribute:	4	7	1	8	1	0
Number of Times Irrelevant for Sets of Attributes:				0		

changes occurred then that uncertainty is said to be irrelevant for that attribute in the subset under consideration. An uncertainty is irrelevant for an entire subset if it is irrelevant for all the attributes. If the uncertainty is irrelevant for all possible subsets, then it is defined to be irrelevant for the entire decision problem.

Not surprisingly, Level 5 danger hour rankings for the strategies are not sensitive to uncertainties unrelated to demand or capacity availability. On the other hand, the strategies switch ranks in every possible subset of the load growth and fuel act uncertainties. In fact, with the exception of the cost attribute (and forced fuel switching in the supply of natural gas uncertainty case) all of the strategy rankings are quite insensitive to the fuel price and base/additions uncertainties. To a large extent this is a result of the assumption in the study regarding the relative cost of fuel (since the relative ranking of the different fuel prices never varied, the loading order of the system's generating units did not change) and the assumption that the additional supply of natural gas would become available with no additional price premium.

In general, the search for irrelevant uncertainties is not a critical component of the trade off framework. As the number and complexity of the futures and strategy sets increases it will become increasingly difficult to find an uncertainty that is truly irrelevant. It is useful, however, for two particular purposes: first, an analysis such as the one performed in the preceding paragraph will assist the participant in considering the effects of certain assumptions on the nature of the trade offs that will be faced in the next stage of the analysis, and, second, an irrelevancy analysis for a smaller group of futures that are believed to be more likely (perhaps during an Advisory Group's heated discussion) could present firmer conclusions.

Section 10 Trade Off Analysis

The trade off analysis stage is central to the IRP process. The questions that the participant addresses here are: What trade offs must be incurred for different attributes in choosing plan 1 over plan 2? How does this vary across the many possible futures? In order to simplify the process, the techniques described in this section will focus on comparing only two strategies at a time (but utilizing all of the attributes).

Earlier studies using the IRP process, such as the one described in Section 3, have focused on the percentage change of an attribute as a measure of the trade off incurred in selecting one strategy over another. This can be a misleading approach. The participant should be exploring the explicit or absolute change to an attribute, not a relative measure such as a percentage change. Percentages simply add another dimension of haze to the analysis by obscuring the actual values that the attributes were designed to measure. It is also faulty to argue that a percentage figure allows direct comparisons between attributes - a 100% percent change in an attribute may represent only a minor change to the system in the eyes of a participant, while a 1% change may reflect a huge impact. As a result, MATOF uses the deviations between attribute values (expressed in the units of measure for each attribute) as the basic trade off unit.

Four different methods are presented in this section that can assist participants in understanding the trade offs:

1) Performance profiles for selected futures

2) Dominance comparisons

3) Trade off vectors and associated statistics

4) Wilcoxon Rank Test for pairwise comparisons

These methods serve a variety of purposes. The performance profiles are a visual tool for assessing the relative performance of different strategies for a single future. Dominance comparisons are an extension of the generation of efficient sets limited to two strategies at a time. This pairwise comparison shows the relative strength of the strategies and is a good complement to the trade off vector, which is a measure based on averages. The trade off vectors are the core of the trade off analysis and should always be investigated. The Wilcoxon Rank Test is a non-parametric statistical measure, which tests the significance of the differences between two strategies for a single attribute across all futures.

Section 10.1 Performance Profiles

A performance profile is a graphical method for comparing a number of strategies across multiple criteria. Each attribute is scaled between zero and one (which becomes the vertical axis)[1] ; the different attributes are listed

[1] Actually, the attributes do not necessarily have to be scaled. They can be put on an individual axis with the maximum and minimum values as endpoints. However, most graphical software packages do not readily generate such a graph, and it is simpler to scale the data first.

across the horizontal axis. Each strategy is graphed as a line across the attributes.

The selected scaling technique will have a significant impact on the readability and interpretation of the performance profiles. The percent scale approach discussed earlier will visually disperse the data at the cost of creating variability that is not present in the data. The linear scale transformation (for minimization type attributes this is calculated as the minimum value of an attribute for a future divided by the attribute value being scaled) is not subject to this problem, but is often harder to read. The two types of scaling are demonstrated in the performance profiles in Figures 19 and 20.

The scaling to be used will depend on the types of attributes. If an attribute exists that has only small variations, but any of which is critically important, it is recommended that the percent scale transformation be utilized. Otherwise, unless the participant has developed an excellent sense of the attribute variations and their significance, it is probably less misleading to use the linear scale transformation.

Performance profiles are the least useful of the tools presented in this section. The problems associated with selecting a meaningful scaling technique and the sheer number that must be considered make performance profiles an awkward process for considering the trade offs across the entire data set. For a limited set of futures, however, performance profiles provide an excellent visual display of trade offs.

Section 10.2 Example: Performance Profiles

The performance profiles in Figures 19 and 20 are based on a future from the AGREA study. Because of the unwieldiness of this approach, the example will be limited to these two figures. Basically, one searches these profiles for visual evidence of dominance and, more importantly, to gain an intuitive feeling for the magnitudes of the trade offs. In Figure 19 (all of the attributes in both graphs are normalized so that 1 signifies the best outcome), Gas20 is clearly a dominated strategy and Gas25, although the figure is difficult to read, is also dominated. For the remaining two strategies, the trade offs must be made between lower values of cost and forced fuel switching and higher values of SO2 emissions and Level 5 danger hours, which is more clearly seen in Figure 20. The difficulty in reading the figures contributes to the weakness of this tool.

Figure .19

Linear Scale Transformation
Performance Profile For Future 1
(Base, M/C, No Act, CELT)

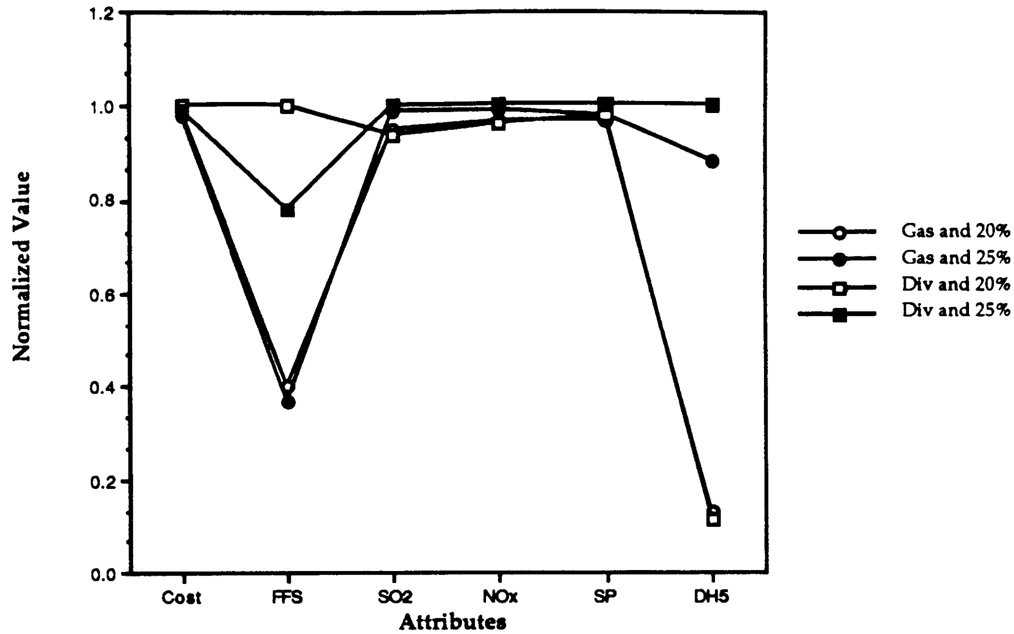
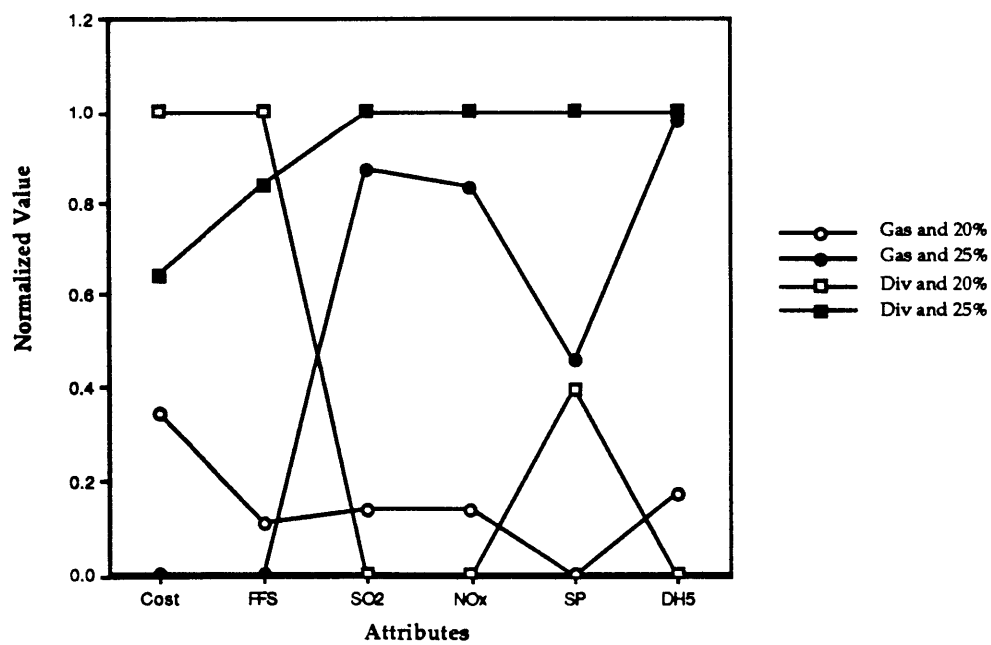


Figure .20

Percent Scale Transformation
Performance Profile For Future 1
(Base, M/C, No Act, CELT)



Section 10.3 Dominance Comparisons

This comparison measure tabulates the number of times that two plans being analyzed dominate the other. The final output for a comparison between plan 1 and plan 2 would look like:

Dominance Comparison

	Plan 1 > Plan 2	Plan 2> Plan 1	Neither dominates
Occurrences:	15	5	12

Clearly, the rows should sum across to equal the number of futures being analyzed. If the probabilities of the futures are available, the entries in the table would be the sum of the probabilities in which that condition occurred. In conjunction with the trade off vector, the dominance comparison allows the participant to assess the "strength" of a plan when compared to another strategy while considering all of the attributes. An example of dominance comparisons using the AGREA study is combined with the trade off vector example following the next section.

Section 10.4 Trade Off Vectors

A trade off vector is defined as the average over all futures of the attribute differences between two strategies. This can be written as:

$$TV_{1\text{-}2} = (1/n)^{*}\Sigma(a_{1f} - a_{2f}) \quad \text{for all } f=1,\ldots,n$$

In the non-uniform case, the probabilities of the futures can be used to calculate an expected value trade off vector. In addition to this vector, other descriptive measures should be displayed for each attribute, such as:

1) Maximum and minimum deviations and the futures in which they occur

2) Standard deviations and coefficients of variation

3) A histogram of the differences

All of these measures can be utilized if probability estimates for the futures are available, as discussed in Section 5.1 on attribute variability.

The trade off vectors and the accompanying statistics are designed to assist the participant in reviewing the trade offs involved in selecting one plan over another. These measures could be calculated for all possible pairs of strategies (if there are m strategies this involves m*(m-1)/2 comparisons).

Section 10.5 Example: Trade Off Vectors and Dominance Comparisons

The results of the trade off vector analysis and the pairwise dominance comparison are presented in Table 13. One of the primary reasons for the number of stages preceding the trade off analysis stage becomes evident here. Even with only four strategies to analyze, the number of pair-wise comparisons across six attributes can become difficult to grasp. The preliminary analysis stages have helped to focus the participant on a smaller subset of strategies and attributes. In our case, I was a priori interested in understanding the trade offs between the Gas20 and Div25 cases. As the example progressed through the data analysis, attribute variability,

Table 13

RELATIVE DIFFERENCE (G20-G25)

	Cost	FFS	SO2	NOx	SP	DH 5
Max	0.03	0.38	0.38	0.13	0.09	1039
Min	-0.05	-5.41	0.07	0.00	0.03	288
Mean	-0.01	-0.96	0.24	0.08	0.06	480
StDv	0.02	1.22	0.09	0.03	0.02	235
CV	-1.55	-1.28	0.36	0.41	0.28	0.49

G20	G25	No D.
0	9	23

#times dominant

RELATIVE DIFFERENCE (G20-D20)

	Cost	FFS	SO2	NOx	SP	DH 5
Max	0.43	18.39	0.17	0.04	0.14	270
Min	-0.08	-0.88	-0.16	-0.08	-0.04	-270
Mean	0.07	4.02	0.00	0.00	0.03	- 9
StDv	0.13	5.59	0.09	0.03	0.06	159
CV	1.89	1.39	-23.08	60.73	1.78	-17.72

G20	D20	No D.
2	9	21

#times dominant

RELATIVE DIFFERENCE (G20-D25)

	Cost	FFS	SO2	NOx	SP	DH 5
Max	0.36	16.65	0.43	0.13	0.20	1068
Min	-0.09	-3.03	0.06	0.01	0.02	72
Mean	0.05	2.56	0.25	0.08	0.09	441
StDv	0.11	4.63	0.11	0.03	0.06	275
CV	2.37	1.81	0.44	0.41	0.62	0.62

G20	D25	No D.
0	17	15

#times dominant

RELATIVE DIFFERENCE (G25-D25)

	Cost	FFS	SO2	NOx	SP	DH 5
Max	0.39	18.32	0.19	0.05	0.14	29
Min	-0.09	-2.11	-0.13	-0.04	-0.05	-217
Mean	0.06	3.51	0.02	0.00	0.03	-40
StDv	0.11	5.07	0.09	0.02	0.06	76
CV	1.87	1.44	5.49	5.04	1.77	-1.91

G25	D25	No D.
2	5	25

times dominant

RELATIVE DIFFERENCE (G25-D20)

	Cost	FFS	SO2	NOx	SP	DH 5
Max	0.44	20.06	-0.06	0.00	0.09	-214
Min	-0.08	-0.39	-0.42	-0.17	-0.11	-969
Mean	0.08	4.98	-0.24	-0.08	-0.03	-489
StDv	0.13	6.12	0.13	0.05	0.06	246
CV	1.63	1.23	-0.55	-0.59	-1.82	-0.50

G25	D20	No D.
6	0	26

times dominant

RELATIVE DIFFERENCE (D20-D25)

	Cost	FFS	SO2	NOx	SP	DH 5
Max	0.03	0.00	0.41	0.14	0.11	998
Min	-0.11	-5.94	0.06	0.01	0.03	74
Mean	-0.02	-1.47	0.26	0.08	0.06	450
StDv	0.03	1.69	0.11	0.04	0.03	277
CV	-1.74	-1.15	0.41	0.44	0.41	0.62

D20	D25	No D.
0	6	26

#times Dominant

robustness, irrelevant uncertainties, and sorting and efficient set generation stages, it became clear that the 25% reserve margin option might be very robust if the cost trade offs are not too steep. If so, then one should focus more on the Gas25 and Div25 trade off comparison.

The first thing we see is that Div25 strongly dominates Gas20 as measured by the pairwise dominance comparison. On average, the trade off vector analysis shows that there is no trade off in moving from Gas20 to Div25. (A positive number in Table 13 indicates that the first number in the pair is larger and thus for this set of attributes an inferior outcome. It follows that a negative number means that the second number in the difference is larger and a worse outcome). We also note that the <u>minimum</u> value in this particular comparison is positive for 4 out of 6 attributes, meaning that Div25 <u>always</u> dominates Gas20 in these cases. It remains to consider the magnitude of the trade offs and, for the dominance comparison, the futures in which the dominance occurs.

Let us address the less critical issue of the dominance comparison. It turns out that all of these 17 dominance examples take place in BB load growths and/or High/Uncoupled fuel price trajectories, both of which I have characterized as less likely. However, since Div25 always dominates Gas20 for the SO2, NOx, SP and Level 5 danger hours attributes, this fact is of little importance. The trade off that must be evaluated is between cost (laying aside forced fuel switching) and the four other attributes. <u>My personal</u> conclusion is that the <u>possible</u> cost penalty is minor compared to the certain gain in the remaining attributes (of course this is only "guaranteed" in the scenarios modeled). Another fact worth considering is that there is a potential for a large cost savings (up to 0.36 ¢/kWh) while the maximum cost increase is only 0.09 ¢/kWh (See the histogram in Figure 21).

Close inspection of Table 13 for cases G20-G25 and D20-D25 shows that exactly the same argument holds for preferring the 25% reserve margin over the 20% case. The only difference is that the magnitudes of the possible cost savings is substantially lower. This suggests that the large cost savings are probably due to moving from Gas20 to Div20. In any case, my preference based on this analysis is to select a larger planning reserve margin.

Figure 21

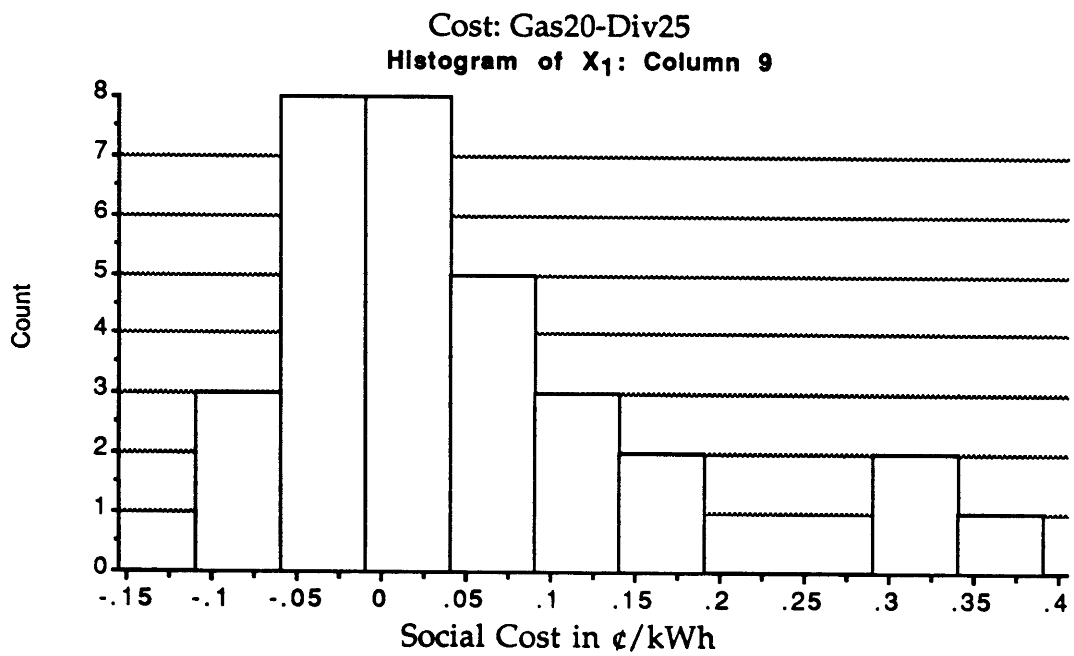


Figure 22

Cost: Div20-Div25

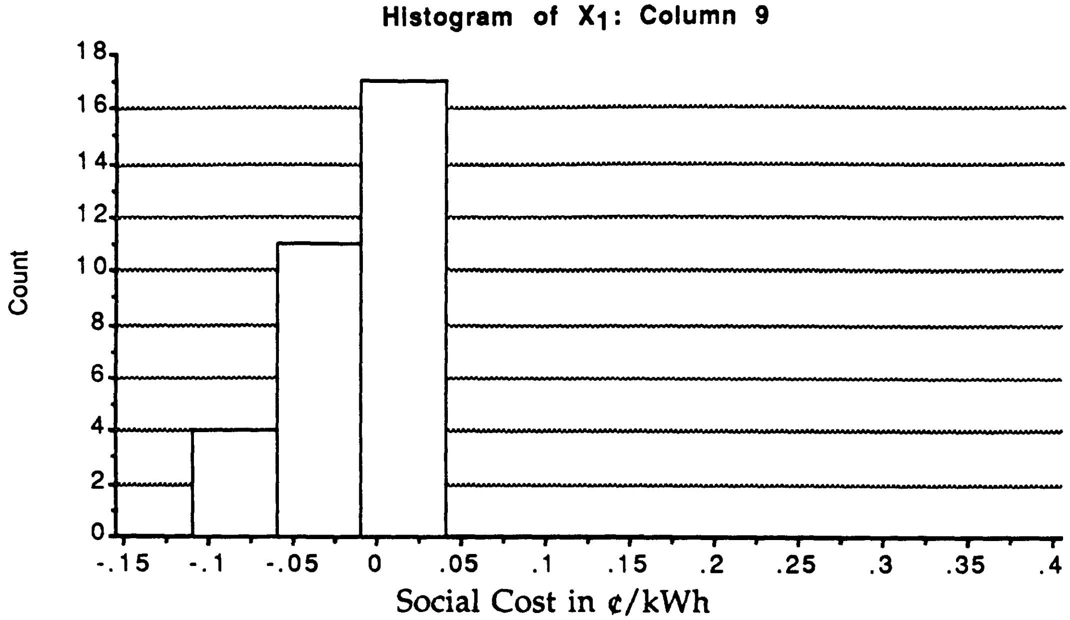
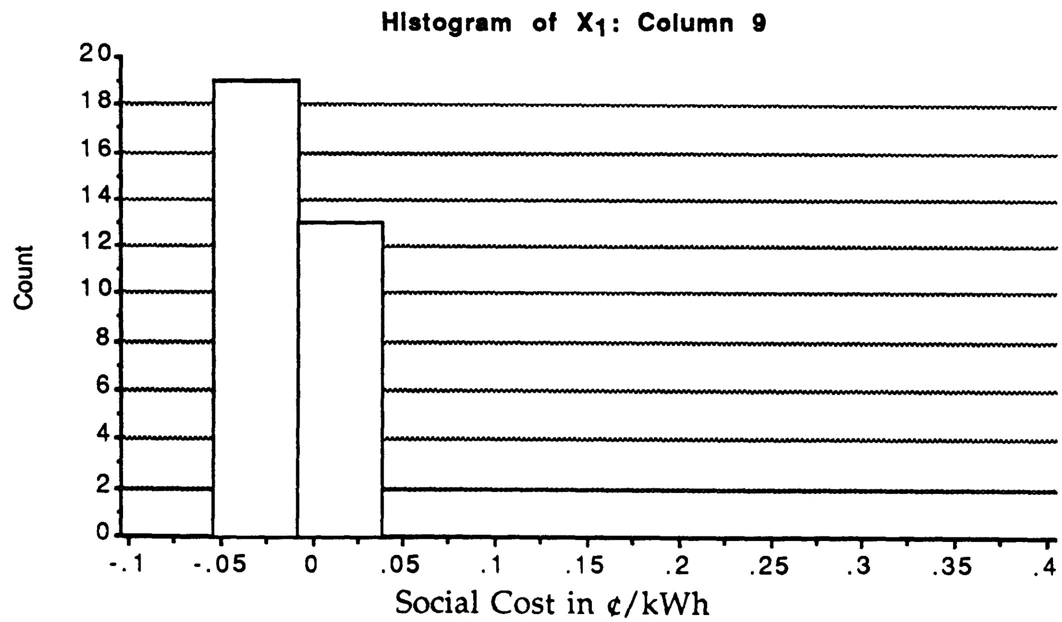


Figure 23

Cost: Gas20-Gas25



The next trade off to focus on in this example, based on the previous results, is the difference between the Gas25 and Div25 strategies. The trade offs are much more difficult here, although we see that, on average, Div25 performs better for every attribute except for Level 5 danger hours. The magnitude of the difference is small, in my subjective estimation, so that if I was doing this analysis solely on the basis of the average differences I would prefer Div25. However, since I believe that some futures are more likely than others, it is worth considering the futures in which some of these differences occur.

The analysis shows that Gas25 outperforms Div25 in futures that were assessed a priori to be relatively unlikely. Div25 performs worse than Gas25 for only 13 of 32 futures with respect to the attribute SO2. This performance is even better when one considers that 12 of these 13 futures included Fuel Act legislation, an uncertainty that I have assessed as unlikely. Div25 is worse in only 9 of 32 futures with respect to cost - six of these are again fuel act cases, the remaining three occur in no act futures with additional gas supplies. Finally, the worst difference with respect to level 5 danger hours is 217 (about three times bigger than the next largest value), which occurs only in futures with fuel acts.

With respect to reliability, since I feel that the average difference of 40 hours over twenty years should not be a difficult burden for industrial customers (especially when substantial improvement has already been made by supporting the 25% reserve margin, and discounted for the occurrences of poor reliability due to the unlikely fuel act futures), I would enter the Advisory Group discussions favoring the Div25 strategy and with a detailed knowledge of the magnitudes of the required trade offs among all the strategies.

Section 10.6 Wilcoxon Rank Test

The Wilcoxon rank test is a non-parametric test (i.e. no assumptions about the underlying population distributions are required) for significant differences between paired observations. It can be extremely difficult for a participant to view and internalize the differences between two strategies across 32 futures, even for a single attribute. The Wilcoxon rank test assists in this task by summarizing the differences in a scalar value that can be statistically tested.

The following discussion demonstrates the nature of this test. For each future, the attribute difference between the plans is calculated (if the difference is zero, the observation is dropped from the sample). These are then ranked according to the absolute value of this difference, with the smallest value assigned rank one. If rankings are tied, the average ranking is used for both. The rankings for positive differences and negative differences are then summed to find $\Sigma+$ and $\Sigma-$. The null hypothesis is H_O: $\Sigma+ = \Sigma-$, i.e., the population positive and negative differences are symmetrically distributed about zero. The smaller of the sums is selected as the test statistic, known as Wilcoxon's T statistic. Appendix A includes a table of critical values for this statistic.

When the number of pairs is greater than 25, T is approximately normal with:

$$\text{Mean, } \mu = n(n+1)/4$$

$$\text{Standard Deviation, } s = \sqrt{(n(n+1)(2n+1)/24)}$$

Therefore, we can calculate a standard normal statistic:

$$z = (T - \mu)/s$$

and carry out the test using the critical values from the standard normal table, which is also included in Appendix A.

This test has the disadvantage of being somewhat black box. In addition, it gives each paired observation equal weight in the derivation of the test statistic, which does not allow it to deal with the non-uniform probability case for the futures. However, this test does provide a clear statistical test for the superiority of one strategy over another for a particular attribute. A Wilcoxon statistic matrix could also be calculated for all possible pairwise comparisons. This measure may be particularly useful if statistical documentation is requested to support a final selection, if one is made. Note, however, that the existence of a statistically significant advantage of strategy 1 over 2 for one attribute but no significant difference across the others does not imply that strategy 1 must be better than 2. This is still a matter of personal judgement. The Wilcoxon test's most important contribution is summarizing the differences of two strategies across a large number of futures and presenting a statistical scalar measure of the significance of the variation

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Section 10.7 Example: Wilcoxon Test Statistic

Table 14 displays the Z-statistics for all of the pairwise strategy comparisons across all of the six attributes. As a rough rule of thumb, a Z-statistic value of two or larger allows us to reject the null hypothesis of no significant difference between the paired samples with a confidence level of 95%. Of particular interest is the Gas20-Div25 comparison. The T statistic is significant for all the attributes except cost[1].

Table 14

The Pairwise Wilcoxon Test Matrix for the AGREA Study

Strategy Comparison	Societal Cost (¢/kWh)	Forced Fuel Switching (Percent)	SO2 Emissions (MM tons)	NOx Emissions (MM tons)	SP Emissions (MM tons)	Level 5 Danger Hours (Cumul. hrs)
D20-D25	2.787	3.920	4.940	4.937	4.937	4.937
G20-D20	2.705	3.421	0.228	0.252	2.832	0.075
G20-D25	1.851	2.873	4.930	4.937	4.937	4.937
G20-G25	2.859	3.808	4.937	4.782	4.937	4.937
G25-D20	3.123	3.696	4.937	4.782	2.979	4.937
G25-D25	2.557	3.458	0.897	0.793	2.599	2.880

The comparison between Gas25 and Div25 illustrates the disadvantage of the Wilcoxon rank test addressed earlier, namely the equal weighting of paired observations (i.e. futures). As the mean difference of the trade off vector component for the SO2 attribute suggests might occur, the Wilcoxon T statistic for this comparison is not significant. However, as a closer look at the futures in which the differences occurred proved, the Div25 strategy performed much better than the Gas25 one in futures which I assessed as more likely.

[1] Given the number of observations (i.e. 32 futures) the largest possible value for this statistic is about 4.95, which occurs when a strategy dominates the other. Some perfectly dominated comparisons can have slightly lower values depending on the number of ties in the comparisons.

Section 11 Conclusion

An open-minded and careful application of the techniques and framework discussed in this chapter will allow the participant to explore the weaknesses and strengths of a variety of strategies across many attributes and measured across a wide spectrum of possible futures. It is simple to use and understand and meets all of the requirements of the Integrated Resource Planning process presented in the beginning of this paper.

The application of this framework to a 1988 Energy Laboratory study served to illustrate the flow of the analysis and the interrelationships among the various components of the framework. The trade off analysis stage - focusing on the trade off vectors and the pairwise dominance comparisons - is at the heart of the framework. These tools allow the participant to explore the set of trade offs that are available given the specified group of options and strategies, rather than trying to select a strategy that somehow maximizes a difficult to determine preference structure.

The trade off framework depends critically on the successful completion of the previous stages. As the example demonstrated, despite the relatively simple approach purposefully taken in the trade off stage, the comparisons can become difficult to grasp, even in a study with a limited number of strategies and attributes. In order to facilitate the analysis, the participant must be guided through the data in a structured way - first exploring his/her a priori beliefs (baring the soul, so to speak), then considering the attribute variability to place the trade offs in a more global context, followed by examining the strategies for generally good or poor performance utilizing the efficient sets and applying sorting techniques, and eliminating any irrelevant uncertainties (in the unlikely event that any exist).

The multiple attribute trade off analysis framework proposed is a flexible and comprehensive tool that allows the participant to explore the strategies and their trade offs in an efficient and enlightening manner. The "output" of the different stages flows naturally to the next and is in a format that is useful for discussion and negotiation within the Advisory Group. Trade off analysis is a critical tool for developing consensus in an adversarial planning process. It is hoped that the tools and framework proposed here add to the feasibility of such analysis and to the insights it provides.

There are two major conclusions that can be drawn from the work in this thesis. The first concerns the emphasis that has been placed on the role of dominance in trade off analysis. The second deals with the requirements that trade off tools and structures must satisfy in the IRP process.

The concept of dominance and the use of the resulting efficient sets to do trade off analysis has been heavily emphasized in the literature [see RISKMIN, 1988 or Schweppe and Merrill, 1987, for example]. The structure proposed in this thesis, however, suggests that dominance is not a sufficient, nor even a particularly necessary, tool for trade off analysis. Although it has a role in framing the pair-wise comparisons (recall the pair-wise dominance analysis in the proposed framework) and is a useful concept in thinking about the data, dominance is no more critical to the process than sorting[1]. This is due primarily to its inadequacies in application. Assuming a large number of futures, it is likely that the global efficient set will contain all of the strategies, which makes the goal of identifying and eliminating dominated strategies difficult. The local efficient sets do provide more information than the global set. However, beyond the summary statistics utilized in the proposed framework, the effectiveness of carefully combing through a large number of local efficient sets is questionable.

Finally, the most important result of this work is understanding and emphasizing the importance of the part that the participant plays in the trade off analysis. The underlying proposition of the proposed structure is that the trade off technique must be centered around human judgements about the reasonableness of trade offs in attributes required by different strategies. For example, any concurrent comparisons of more than two strategies (i.e. moving beyond pair-wise comparisons) must be in a form that can be interpreted by the participant and allows them to judge the trade offs. In other words, a weighting scheme or programmed technique which takes the analysis and evaluation out of the hands of the participant is not appropriate and is likely to fail.

[1] In fact, as demonstrated by the theory behind the Robustness stage, dominance can prove to be misleading if applied indiscriminately.

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Appendix A

Critical Values of Wilcoxon's T statistic

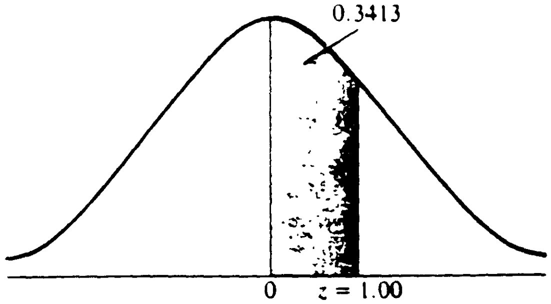
The symbol *T* denotes the smaller sum of ranks associated with differences that are all of the same sign. For any given *N* (number of ranked differences), the obtained *T* is significant at a given level if it is equal to or *less than* the value shown in the table.

	Level of Significance for One-tailed Test					Level of Significance for One-tailed Test			
	0.05	0.025	0.01	0.005		0.05	0.025	0.01	0.005
	Level of Significance for Two-tailed Test					Level of Significance for Two-tailed Test			
N	0.10	0.05	0.02	0.01	N	0.10	0.05	0.02	0.01
5	0	—	—	—	28	130	116	101	91
6	2	0	—	—	29	140	126	110	100
7	3	2	0	—	30	151	137	120	109
8	5	3	1	0	31	163	147	130	118
9	8	5	3	1	32	175	159	140	128
10	10	8	5	3	33	187	170	151	138
11	13	10	7	5	34	200	182	162	148
12	17	13	9	7	35	213	195	173	159
13	21	17	12	9	36	227	208	185	171
14	25	21	15	12	37	241	221	198	182
15	30	25	19	15	38	256	235	211	194
16	35	29	23	19	39	271	249	224	207
17	41	34	27	23	40	286	264	238	220
18	47	40	32	27	41	302	279	252	233
19	53	46	37	32	42	319	294	266	247
20	60	52	43	37	43	336	310	281	261
21	67	58	49	42	44	353	327	296	276
22	75	65	55	48	45	371	343	312	291
23	83	73	62	54	46	389	361	328	307
24	91	81	69	61	47	407	378	345	322
25	100	89	76	68	48	426	396	362	339
26	110	98	84	75	49	446	415	379	355
27	119	107	92	83	50	466	434	397	373

Source: Hamburg, Morris, Statistical Analysis for Decision Making (3rd Ed.), Harcourt Brace Jovanovich, Inc., New York, 1983.

Appendix A

Areas Under the Standard Normal Probability Distribution



Example If z = 1.00, then the area between the mean and this value of z is 0.3413.

z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0.0000	0.0040	0.0080	0.0120	0.0160	0.0199	0.0239	0.0279	0.0319	0.0359
0.1	0.0398	0.0438	0.0478	0.0517	0.0557	0.0596	0.0636	0.0675	0.0714	0.0753
0.2	0.0793	0.0832	0.0871	0.0910	0.0948	0.0987	0.1026	0.1064	0.1103	0.1141
0.3	0.1179	0.1217	0.1255	0.1293	0.1331	0.1368	0.1406	0.1443	0.1480	0.1517
0.4	0.1554	0.1591	0.1628	0.1664	0.1700	0.1736	0.1772	0.1808	0.1844	0.1879
0.5	0.1915	0.1950	0.1985	0.2019	0.2054	0.2088	0.2123	0.2157	0.2190	0.2224
0.6	0.2257	0.2291	0.2324	0.2357	0.2389	0.2422	0.2454	0.2486	0.2518	0.2549
0.7	0.2580	0.2612	0.2642	0.2673	0.2704	0.2734	0.2764	0.2794	0.2823	0.2852
0.8	0.2881	0.2910	0.2939	0.2967	0.2995	0.3023	0.3051	0.3078	0.3106	0.3133
0.9	0.3159	0.3186	0.3212	0.3238	0.3264	0.3289	0.3315	0.3340	0.3365	0.3389
1.0	0.3413	0.3438	0.3461	0.3485	0.3508	0.3531	0.3554	0.3577	0.3599	0.3621
1.1	0.3643	0.3665	0.3686	0.3708	0.3729	0.3749	0.3770	0.3790	0.3810	0.3830
1.2	0.3849	0.3869	0.3888	0.3907	0.3925	0.3944	0.3962	0.3980	0.3997	0.4015
1.3	0.4032	0.4049	0.4066	0.4082	0.4099	0.4115	0.4131	0.4147	0.4162	0.4177
1.4	0.4192	0.4207	0.4222	0.4236	0.4251	0.4265	0.4279	0.4292	0.4306	0.4319
1.5	0.4332	0.4345	0.4357	0.4370	0.4382	0.4394	0.4406	0.4418	0.4429	0.4441
1.6	0.4452	0.4463	0.4474	0.4484	0.4495	0.4505	0.4515	0.4525	0.4535	0.4545
1.7	0.4554	0.4564	0.4573	0.4582	0.4591	0.4599	9.4608	0.4616	0.4625	0.4633
1.8	0.4641	0.4649	0.4656	0.4664	0.4671	0.4678	0.4686	0.4693	0.4699	0.4706
1.9	0.4713	0.4719	0.4726	0.4732	0.4738	0.4744	0.4750	0.4756	0.4761	0.4767
2.0	0.4772	0.4778	0.4783	0.4788	0.4793	0.4798	0.4803	0.4808	0.4812	0.4817
2.1	0.4821	0.4826	0.4830	0.4834	0.4838	0.4842	0.4846	0.4850	0.4854	0.4857
2.2	0.4861	0.4864	0.4868	0.4871	0.4875	0.4878	0.4881	0.4884	0.4887	0.4890
2.3	0.4893	0.4896	0.4898	0.4901	0.4904	0.4906	0.4909	0.4911	0.4913	0.4916
2.4	0.4918	0.4920	0.4922	0.4925	0.4927	0.4929	0.4931	0.4932	0.4934	0.4936
2.5	0.4938	0.4940	0.4941	0.4943	0.4945	0.4946	0.4948	0.4949	0.4951	0.4952
2.6	0.4953	0.4955	0.4956	0.4957	0.4959	0.4960	0.4961	0.4962	0.4963	0.4964
2.7	0.4965	0.4966	0.4967	0.4968	0.4969	0.4970	0.4971	0.4972	0.4973	0.4974
2.8	0.4974	0.4975	0.4976	0.4977	0.4977	0.4978	0.4979	0.4979	0.4980	0.4981
2.9	0.4981	0.4982	0.4982	0.4983	0.4984	0.4984	0.4985	0.4985	0.4986	0.4986
3.0	0.49865	0.4987	0.4987	0.4988	0.4988	0.4989	0.4989	0.4989	0.4990	0.4990
4.0	0.49997									

Source: Hamburg, Morris, Statistical Analysis for Decision Making (3rd Ed.), Harcourt Brace Jovanovich, Inc., New York, 1983.