QUANTIFYING OIL DISRUPTION RISKS THROUGH EXPERT JUDGEMENT

EMF SR 7

Hillard Huntington, Antje Kann
John Weyant
ENERGY MODELING FORUM
STANFORD UNIVERSITY

Phil Beccue
APPLIED DECISION ANALYSIS, INC.

April 1997

Energy Modeling Forum
Terman Engineering Center
Stanford University

ABSTRACT

This report describes a methodology for extracting and quantifying expert views on the likelihood of at least one oil disruption over the next ten years. Experts attended a series of workshops held by the Energy Modeling Forum to develop a risk assessment framework for use in understanding key uncertainties in thinking about energy security. This framework draws on decision and risk analysis, methodologies which have been used to analyze a range of different topics where uncertainty is important and where objective and rigorous standards can hold up to scrutiny by a variety of affected parties.

The approach identified uncertain events in three broad areas that spanned political and military conditions, oil shortfalls, and potential supply offsets. Participating experts evaluated uncertainties associated with a number of conditions that could influence the magnitude of an oil disruption. These lower-level uncertainties are then combined mathematically to derive an overall assessment of the likelihood of oil disruptions of varying magnitudes. The study addressed both short (less than 6 months) and long (more than 6 months) disruptions.

TABLE OF CONTENTS

Page

LIST OF FIGURES

Page

LIST OF TABLES

Page

OBJECTIVES

The Energy Modeling Forum has organized a series of workshops to develop a risk assessment framework for use in understanding key uncertainties in the energy security arena. The risk assessment framework developed in these meetings draws on decision and risk analysis, methodologies which have been used to analyze a range of different topics where uncertainty is important, and where objective and rigorous standards can hold up to scrutiny by a variety of affected parties. The workshops focused on incorporating expert judgment in the explicit quantification of the magnitude and likelihood of oil disruptions, as members from the several offices of the Department of Energy are specifically interested in understanding the risks of oil shortages of a magnitude sufficient to prompt significant deviations in world oil prices. The objective for this framework is to provide a quantitative, logical, and defensible analysis of these risks.

A meeting of energy security experts was held on November 12-13, 1996 at Marymount University, Arlington, Virginia. The purpose of this meeting was to build on the insights and experiences of previous workshops to:

1) check the validity of the approach with a broader group of experts
2) finalize the framework of the model
3) refine definitions of events and their implications
4) assess probabilities with the experts.

PARTICIPANTS

The workshop was conducted by Phil Beccue from Applied Decision Analysis, Inc., and Hill Huntington, Antje Kann, and John Weyant from the Energy Modeling Forum, Stanford University. The panel of experts consisted of energy security and oil market experts with a broad range of technical expertise, diverse experiences in the key factors that affect energy security, and representing a wide range of institutional/ organizational backgrounds. Panel members were asked to represent their individual judgments and not to act as representatives of technical or policy positions taken by their organizations. The participants included:

Phil Beccue	Applied Decision Analysis
Robert Bidwell	U.S. Department of Energy
Patrick Clawson	National Defense University
Carmen Difiglio	U.S. Department of Energy
Stephen Gallogly	U.S. Department of State
Lawrence J. Goldstein	Petroleum Industry Research Foundation
Hill Huntington	Energy Modeling Forum, Stanford University
Amy Myers Jaffe	Baker Institute for Public Policy
Antje Kann	Energy Modeling Forum, Stanford University

Wilfrid L. Kohl	John Hopkins University
Paul Leiby	Oak Ridge National Laboratory
Elena S. Melchert	U.S. Department of Energy
Mike Ortmeier	U.S. Department of Energy
Edward Porter	American Petroleum Institute
Eric Weil	U.S. Department of Energy
John P. Weyant	Energy Modeling Forum, Stanford University

PROCEDURE

After an introduction to the methodology of risk assessment and training in probability assessment including a series of warm-up questions, the workshop attendees discussed and refined the model structure and event definitions, and then assessed some of the probabilities in a group discussion format. Considerable effort was spent to refine the structure and definition of the regional shortfall events in Saudi Arabia and Iran/Iraq/Kuwait, and the underlying events that influence the shortfall events.

The participants were then divided into three groups according to their data responsibilities: "Saudi Arabia," "Iran/Iraq/Kuwait," and "Offsets and production." The Iran/Iraq/Kuwait group, led by Phil Beccue, consisted of Patrick Clawson, Carmen Difiglio, Larry Goldstein, and Amy Myers Jaffe. The Saudi Arabia group was led by Antje Kann and was attended by Robert Bidwell, Wilfrid Kohl, Mike Ortmeier, Ed Porter, and Steve Gallogly. The Offsets group was led by Hill Huntington and consisted of Erik Weil, Elena Melchert, and Paul Leiby.

The second day consisted of a presentation of the results from the individual working groups, further refinement of some of the inputs, and elicitation of feedback from the participants.

METHODOLOGY

Decision analysis is a set of analytical methods and organizational processes for improved decision making. For the purposes of this study, a distinguishing feature of decision analysis is especially important: a formal treatment of uncertainty. Empirical data is often insufficient to quantify the uncertainty in the consequences faced by a decision or policy maker. Using standard methods of Bayesian probability theory, decision analysis provides a formal quantitative procedure for extracting and quantifying the subjective uncertainty of experts, and for revising and updating the assessments as new information becomes available.

Developed at Harvard and Stanford in the 1960s, decision analysis is now widely taught in universities and practiced in business and government, and has received favorable reviews from the National Academy of Science. Important applications of decision analysis include: helping major oil companies in strategic upstream decisions, assisting the Department of Energy with siting the nuclear waste repository, creating a unified system to prioritize hazardous waste cleanup throughout the DOE complex, developing national ambient air quality standards for the EPA, and understanding the risks of nuclear reactor technologies.

"Risk" is defined as uncertainty regarding future adverse consequences. An example of an adverse consequence is: a 10 MMBD shortfall in production for six months in 2002. Risk assessment serves to determine what the adverse consequences could be and what their likelihoods are. It is the process of quantifying the chances of all possible outcomes. The probability distributions used to describe the uncertainty about adverse consequences can be obtained through historical records, through direct assessments from experts when historical information is insufficient, or through models using a combination of the two approaches.

The decision analysis approach to capturing judgmental uncertainty is to model the assessed quantity in detail by decomposing it into well-defined components, assessing lower level probabilities, and then combining the data mathematically. Advantages of this approach are the fact that assessments are easier, that it facilitates assessments with groups of experts, the quality of assessments tends to be high, and that logic and assumptions are well documented. Disadvantages are a tendency to go too far in the level of detail of modeling the problem, and the fact that the approach is time intensive.

Probability assessments can be viewed as a quantitative representation of a person's knowledge. To ensure that probability assessments obtained from experts are authentic, formal procedures have been developed. These include interview techniques to control motivational or cognitive biases, and methods to assess multiple experts and resolve differences in opinion.

The influence diagram is a useful tool which provides a roadmap for the probability assessment process and which helps to communicate the model framework to everyone involved in the process. It is a graphical representation of a decision or risk analysis problem. Each uncertain event in an influence diagram has 2 or more states, which are mutually exclusive (non-overlapping) and collectively exhaustive (all possibilities included), and each state has an associated likelihood. An arrow pointing to an uncertainty represents probabilistic dependence.

We will use an overly simplifed example of an influence diagram applied to the oil disruption problem to illustrate the meaning of the various elements, the data required for the analysis, and the computations that produce the resulting probability distributions.

Let us begin by looking at an uncertain event, expressed as a circle or oval. Figure 1 shows an event which captures the uncertainty surrounding the size of a shortfall in oil production in Saudi Arabia.

Figure 1. Example of an Uncertain Event

Uncertain events in an influence diagram have a precise meaning. Because its value is unknown to the decision maker, an uncertain event must have two or more states. Furthermore, the states must be mutually exclusive and collectively exhaustive. Figure 2 shows the states of the event in Figure 1.

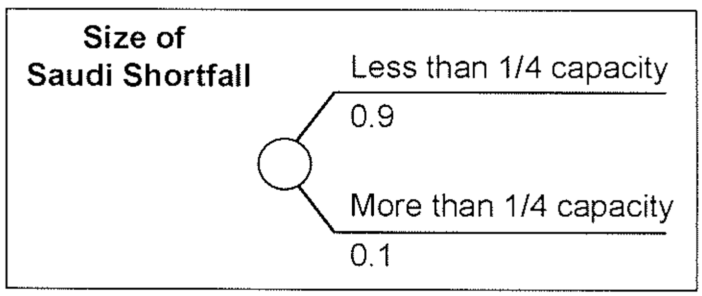

Figure 2. States of an Uncertain Event

There are 2 branches because the uncertain event in Figure 1 was characterized by two states. By convention, the name of the state is placed above the branch, and the probability associated with that state below the branch. The mutual exclusivity condition means that the states may not overlap. For example, in Figure 2 we could not have the following two states since they overlap:

- less than 1/4 capacity
- more than 90% of capacity.

The collectively exhaustive condition means that all possibilities must be included. In Figure 2, we could not have the states

- less than 1/4 capacity
- more than 1/2 capacity

since we have not included disruption sizes between 1/4 and 1/2 of capacity. Finally, each state of an event is assigned a likelihood of occurring, and from the above conditions, the sum of the likelihoods must equal one.

An event with no predecessors, that is, no arrows pointing to it, is an independent variable. The probability assignments provided by the experts for this event are independent of any other factors or variables. However, dependencies among events often dominate the results of a risk analysis, and therefore careful attention is given to specifying and quantifying the degree of dependence among events. Figure 3 shows an event that influences the size of a Saudi shortfall.

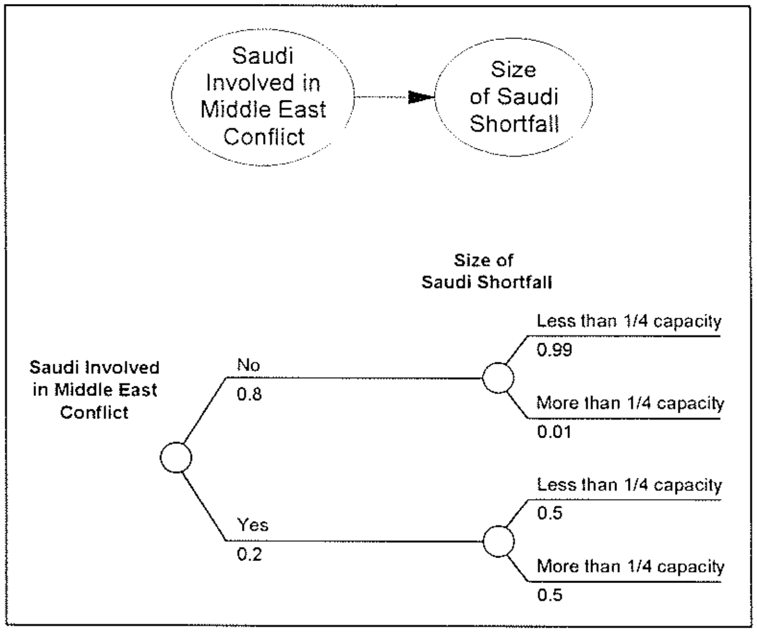

Figure 3. Example of probability assignments for dependent events

An arrow pointing to an uncertainty represents probabilistic dependence. In this case, the probability assignments for Size of Saudi Shortfall depend on whether or not Saudi Arabia is involved in a Middle East conflict. It is very important to capture these types of dependencies in a risk assessment.

The development of an influence diagram involves identifying events, deciding on appropriate states for each event, determining the dependencies among events, and assigning likelihoods to the states of each event. Once these steps are accomplished, we are ready to perform the analysis that will compute the resulting probability distribution on any variable of interest. For this study, the primary variable of interest is Net Disruptions. We will use another simplied example to show how the calcuations are performed.

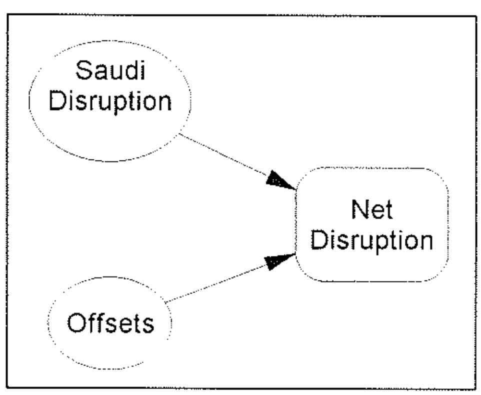

Figure 4. Sample influence diagram

Figure 4 shows two independent events which influence the computation of the value "Net Disruption." The equation for net disruption, which is measured as "percent world production," is:

Net Disruption = (Saudi Disruption - Offsets)/World Production.

Suppose that total world production is 50 million barrels per day (MMBD). Let the Saudi Disruption event be defined with three states (None, Moderate, All) and the Offsets event with two states (Low, High). To perform the risk assessment, it is necessary to examine all combinations of all event states. For this simple example, we have six scenarios as shown in Figure 5. The probabilities are shown beneath each branch on the probability tree.

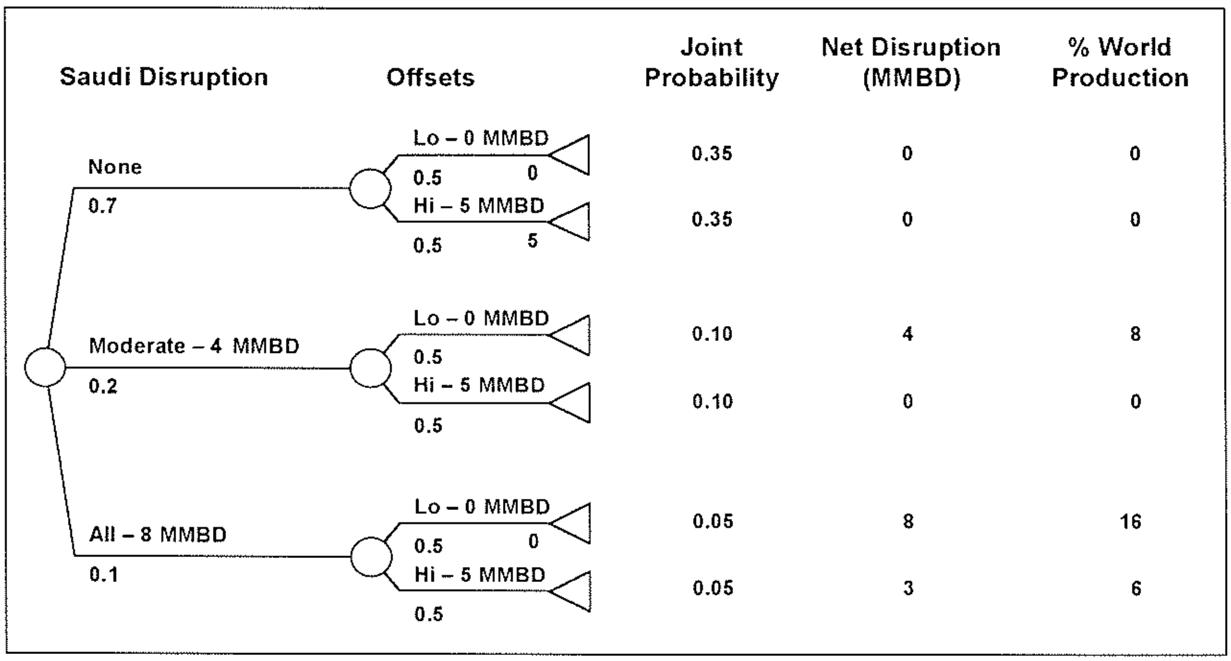

Figure 5. Probability tree for performing risk assessment computations

For each scenario, we compute the joint probability by multiplying the probabilites on the branches. We also compute the Net Disruption for each branch by invoking the equation above. Then, with probability value pairs for each branch, we can plot the probability density function to summarize the impacts and likelihoods of all possible scenarios (Figure 6).

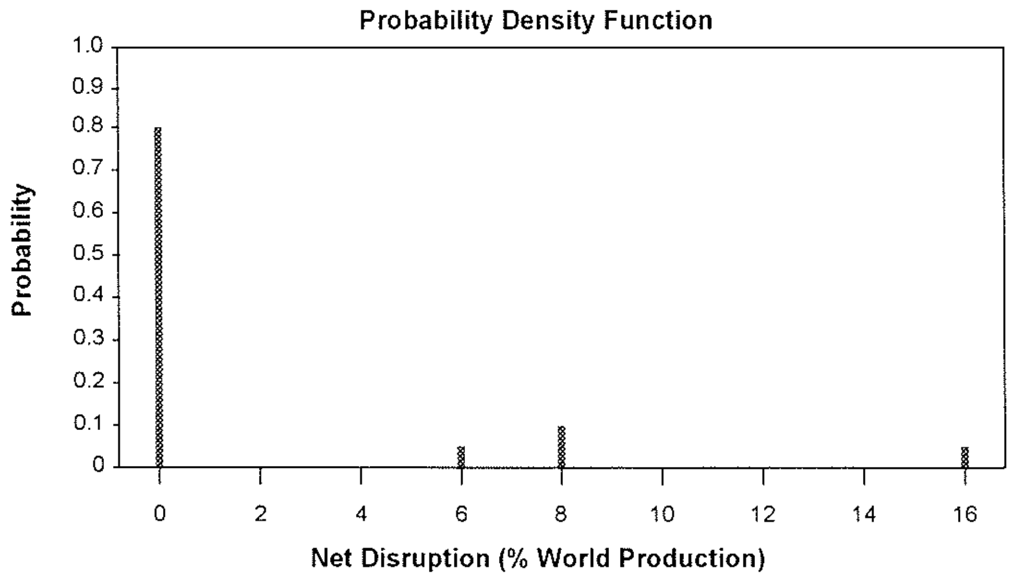

Figure 6. Probability density function for "Net Disruption"

The probability density function shows the probability of a scenario as the height of the line for a given percent net disruption. With more scenarios, these functions may look like the typical bell-shaped curves familiar to many people. The cumulative probability distribution is a much more useful representation of the same result. Figure 7 shows the same distribution in cumulative form. For a given value of net disruption on the horizontal axis, the corresponding probability is the likelihood that the actual value is less than or equal to the net disruption. For example, the chance that there will be a net disruption of size equal to 7% of world production or less is 85%. This includes all disruption sizes from 0 up to 7% of world production. The converse statement is stated as follows: "the chance that there will be a net disruption of size equal to or greater than 7% of world production is 15% (1–0.85).

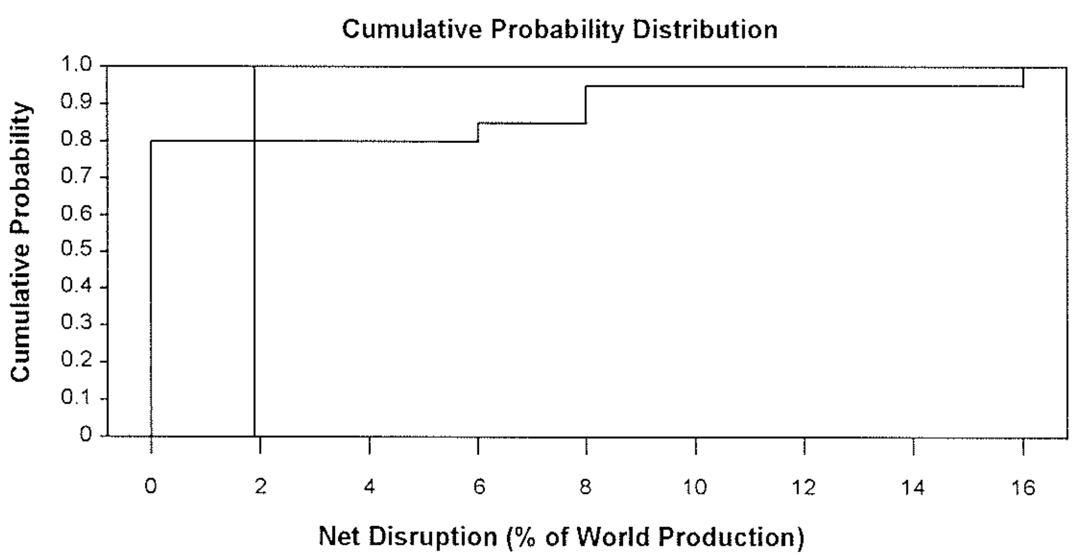

Figure 7. Cumulative probability distribution for "Net Disruption"

In the oil disruption risk assessment, note that the likelihood for no disruption is the height of the vertical line at 0. In this simple example, the chance of no disruption is 80%.

For this small problem with only two events and 6 scenarios, it is straightforward to translate probability assessments of uncertain events into resulting probability distributions. In the actual model with nearly 20 events and over 750,000 scenarios, the cumulative probability distribution is a powerful way to compactly communicate the results of the assessments.

MODEL STRUCTURE

The influence diagram developed for the oil security risk assessment framework captures the key factors affecting oil disruption risks and the dependencies between these factors. The influence diagram reflecting the inputs of the November 1996 workshop participants is shown in Figure 8.

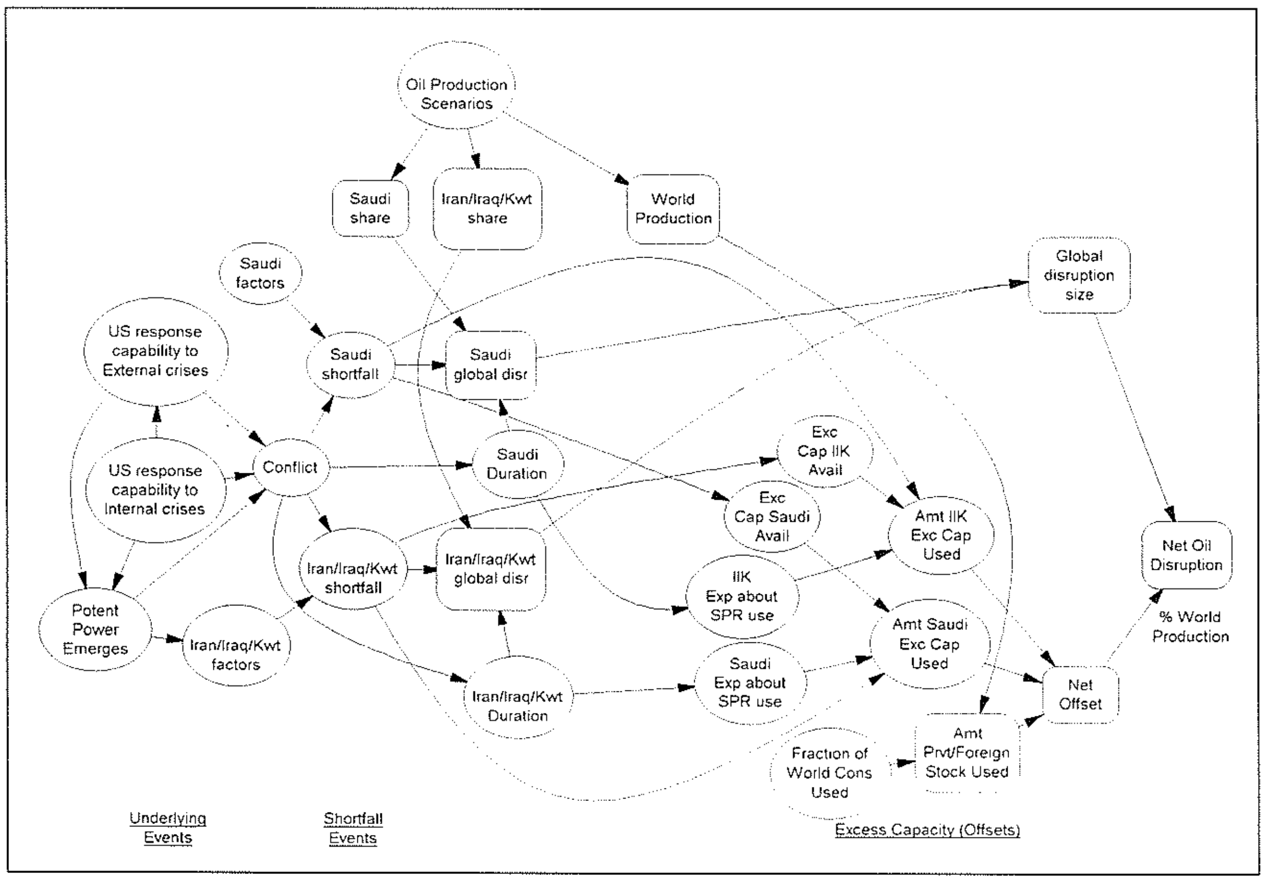

Figure 8. World Oil Disruption Influence Diagram.

The rounded rectangles represent calculated quantities, while the ovals represent uncertain variables. The model was developed and refined through a series of meetings and discussions with energy security experts. This diagram captures the primary events that could lead to major world oil disruptions in a form conducive to data input and analysis. The influence diagram has underlying events on the left leading to shortfall events in the middle. Shortfalls are offset by excess capacity on the lower right. Key underlying events impact shortfalls in two dominant regions (Saudi Arabia and Iran/Iraq/Kuwait). Combined with oil production and excess capacity estimates, a measure of net oil disruptions can be computed.

Each of the uncertain variables, or ovals on the influence diagram, require probability assessments from experts. Before assessing probability estimates, it is very important to have a clear definition of each variable. Most of the variables are measured by a scale with two or more discrete levels. Care was taken by the experts to review the variable definitions and associated scales before providing probability assessments. The results of the event definitions and scales are summarized in the next section.

EVENT DEFINITIONS

1a. U.S. Response Capability to Internal Crisis:

The US has and is perceived to have the will and capability to orchestrate a timely and effective response (military or diplomatic) to an internal crisis. The scale for this event consists of two levels:

1) 100% effective
2) 0% effective.

1b. U.S. Response Capability to External Crises

The US has and is perceived to have the will and capability to orchestrate a timely and effective response (military or diplomatic) to an external crisis. The scale for this event consists of two levels:

1) 100% effective
2) 0% effective.

2. Potent Power Emerges

A potent power emerges in the middle east and is perceived as a credible threat. The scale for this event consists of two levels:

1) Yes
2) No.

3. Conflict

The state of affairs in the middle east in terms of the level of conflict that exists at the time of a disruption. The scale for this event consists of the following levels:

1) Neutral; no major military conflict in Gulf or armed conflict in Gulf between little players.
2) Armed conflict or embargo in Gulf between big player and Iran/Iraq but not Saudi Arabia.
3) Armed conflict in Gulf involving multiple big players.
4) Either 2) or 3) above and other major external conflict, includes non-Gulf military intervention, Israeli war, etc.

4. Saudi Factors

The state of internal affairs in Saudi Arabia that exists at the time of a disruption. The scale for this event consists of the following levels:

1) Status quo; moderate internal problems, stable internal
2) More severe internal problems (e.g., turnover in royal family)
3) Either 1) or 2) and intentional reduction of oil production.

5. Saudi Shortfall

A sudden disruption in oil production from Saudi Arabia that results in at least 3 MMBD unavailable within one month of the beginning of the disruption. The shortfall has a duration of at least 1 month. The disruption occurs at least one time during the 10-year period 1997–2006. The scale for this event consists of the levels:

1) None
2) Small (33%)
3) Large (75%)
4) All (100%).

6. Saudi Duration

The duration of a Saudi shortfall, given that a disruption has occurred. This event addresses the question: "Given that Saudi production facilities have been disrupted for the past 30 days, what are the chances it will last longer than 6 months?" The scale for this event consists of two levels:

1) Short (≤ 6 months)
2) Long (> 6 months).

7. Iran/Iraq/Kuwait (I/I/K) Factors

The state of internal affairs in Saudi Arabia that exists at the time of a disruption. The scale for this event consists of the following levels:

1) Status Quo: moderate social problems, stable internal affairs; no worse than current situation
2) More severe internal social problems in one or more of I/I/K.
3) I/I/K intentional reduction of oil production.

8. Iran/Iraq/Kuwait Shortfall

A sudden shortfall in oil production from Iran, Iraq, and/or Kuwait that results in at least 3 MMBD unavailable within 1 month of the beginning of the disruption. The shortfall has a duration of at least one month. The disruption occurs at least one time during the 10-year period 1997–2006. The scale for this event consists of the levels:

1) None
2) Small (33%)
3) Large (75%)
4) All (100%).

9. Iran/Iraq/Kuwait Duration

The duration of an Iran, Iraq, and/or Kuwait shortfall, given that a disruption has occurred. This event addresses the question: "Given that Iran, Iraq, or Kuwait production facilities have been disrupted for the past 30 days, what are the chances it will last longer than 6 months?" The scale for this event consists of two levels:

1) Short (≤ 6 months)
2) Long (> 6 months).

10a. Saudi Expectations About SPR Use

At the time of a disruption, Saudi Arabia either expects the U.S. to release a portion of SPR reserves to the world market, or Saudi Arabia does not expect the U.S. to release SPR reserves. The scale for this event consists of two levels:

1) Expect
2) Don't Expect.

10b. Iran/Iraq/Kuwait Expectations About SPR Use

At the time of a disruption, Iran/Iraq/Kuwait producers either expect the U.S. to release a portion of SPR reserves to the world market, or Iran/Iraq/Kuwait producers do not expect the U.S. to release SPR reserves. The scale for this event consists of two levels:

1) Expect

2) Don't Expect.

11a. Excess Capacity from Saudi Arabia Available

The amount of excess oil production capacity (MMBD) available in Saudi Arabia midway through the 10-year period 1997 - 2006. The capacity must be capable of being delivered to the world market within 1 month of a disruption. The scale for this event consists of the levels

1) None

2) Medium

3) High.

11b. Excess Capacity from Iran/Iraq/Kuwait Available

The amount of excess oil production capacity (MMBD) available in Iran/Iraq/Kuwait midway through the 10-year period 1997-2006. The capacity must be capable of being delivered to the world market within 1 month of a disruption. The scale for this event consists of the levels

1) None

2) Medium

3) High.

12a. Amount of Saudi Excess Capacity Used

The amount of excess oil production capacity in Saudi Arabia at the time of a disruption that the Saudis actually deliver to the world market within 1 month of a disruption. It is conceivable that the Saudis will not release a portion of their reserves during a disruption. The scale for this event consists of the levels

1) Use Little (<25%)

2) Use Half (25-75%)

3) Use All (>75%).

12b. Amount of Iran/Iraq/Kuwait Excess Capacity Used

The amount of excess oil production capacity in Iran/Iraq/Kuwait at the time of a disruption that they actually deliver to the world market within 1 month of a disruption. It is conceivable that Iran/Iraq/Kuwait will not release a portion of their reserves during a disruption. The scale for this event consists of the levels

1) Use Little (<25%)

2) Use Half (25-75%)

3) Use All (>75%).

13. Amount of Private/Foreign Stock Used

The percentage of available private and foreign stock at the time of a disruption that is delivered to the world market within 1 month of a disruption. The scale for this event consists of the levels

1) Low
2) Medium
3) High.

14. Oil Production Scenarios

Three oil production scenarios are representative of the future uncertainty in oil price and world share of production. For the 10-year period 1997-2006, we approximated production scenarios for the years 2000, 2005, and 2010, taken from the Energy Information Administration's *International Energy Outlook*, 1995. The scale for this event consists of the levels

1) Low Q (price in 2010 = $14.50)
2) Middle Q (price in 2010 = $24)
3) High Q (price in 2010 = $30).

RESULTS OF THE ASSESSMENTS

The detailed probability data obtained from the experts are listed in the Appendix A. This information was entered into DPL software, a state-of-the-art decision and risk analysis package. To obtain summary information, the model calculated the disruption size for all combinations of event states (750,000 scenarios) and weighted each scenario by its likelihood of occurrence.

The primary result obtained from the analysis is a distribution on the percent of world production disrupted. The cumulative distributions for six months or greater and one year or greater, based on the data assessed from the experts at the workshop, are shown in Figure 9 below. The cumulative probability is the probability that the actual Percent of World Production Disrupted will be less than or equal to the percent world production on the horizontal axis. (Note: these results are preliminary based on informal group assessments within tight time constraints. However, they represent an approximation of the combined expertise among the participants based on current world conditions.)

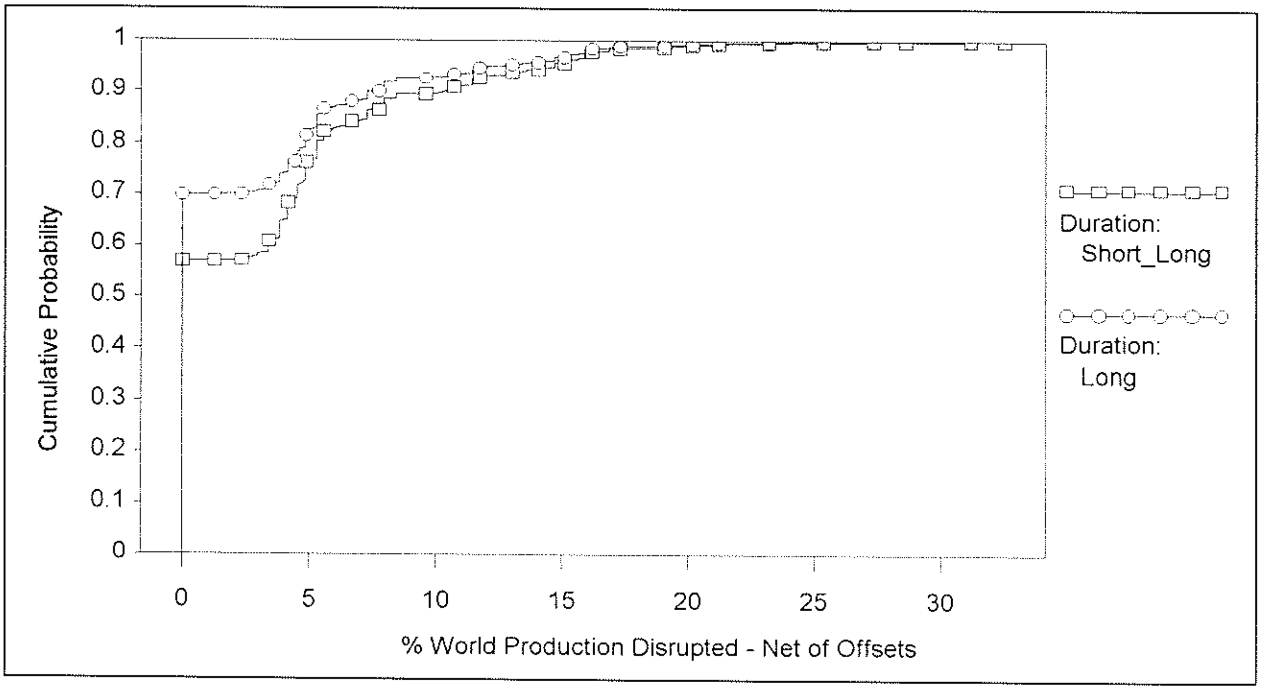

Figure 9. Preliminary Risk Assessment of an Oil Disruption.

The probability distributions in Figure 9 communicate in a compact form the combined thinking of the experts' opinions about the risk of major oil disruptions. According to the figure, the probability of no long disruption is 70%, or conversely, the experts believe there is a 30% chance of a long (greater than 6 month) disruption of some magnitude in the next 10 years. Shorter duration disruptions are more likely. The probability of a 6 month or less disruption over the next 10 years is 43%. We can also conclude that the likelihood of disruptions greater than 20% of world production are 1%, and the likelihood of disruptions greater than 30% world production are one in one thousand.

The probability distribution in Figure 9 conveys additional insights. For example, there is very little difference in duration for net disruptions greater than 5% world production. In other words, most large disruptions will tend to be of longer duration. In the flat region between 0% and 3%, the small disruptions tend to be mitigated by offsets. Furthermore, the analysis reports the expected value of each distribution. For long disruptions, the expected size of a disruption is 2.2% of world production, and for combined short and long disruptions the expected size is 3.2% of world production.

To test the effect that variations in probabilities of different events have on the outcome of the model, a sensitivity analysis was performed on the events' probabilities. The sensitivity analysis revealed that the quantity of the expected oil disruption varied less with variations in probabilities related to offsets than with the probabilities assessed for the political events relating to conflicts and shortfalls. Consequently, during the workshop the facilitators placed particular emphasis on ensuring that the model correctly captures the political dynamics, and that the probabilities assessed for these key variables reflect the experts' true opinions.

Other types of calculations can be performed to obtain distributions on quantities of interest. For example, the probability distributions for "Saudi Shortfall" and "Iran/Iraq/Kuwait Shortfall" are shown in Figure 10. These probability distributions reflect the combined probabilities of the shortfall event assessments and underlying event assessments.

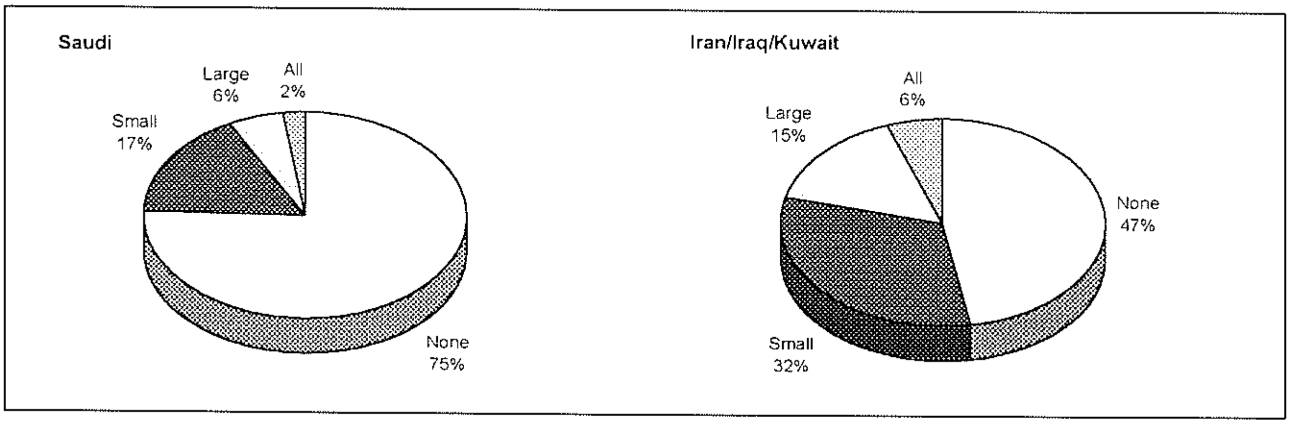

Figure 10. Probability Distributions for Shortfall Events.

Another interesting distribution is the conflict event shown in Figure 11, which depends on the U.S. Response Capability to Internal and External Crises, and whether a potent power emerges.

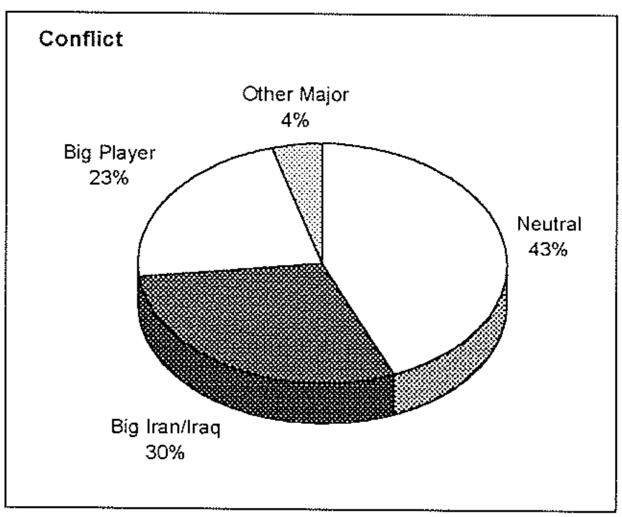

Figure 11. Probability Distribution for "Conflict" Event.

COMPARISON WITH PREVIOUS WORKSHOP SESSIONS

The initial risk assessment framework was developed through a series of meetings and discussions with energy security experts. The primary purpose of these meetings was to develop detailed influence diagrams that identify the key factors contributing toward oil disruption risks, and the relationships between these factors. The detailed risk assessment model was translated into a smaller, condensed influence diagram to make the data assessments feasible. The output from these meetings was a consensus view on the detailed influence diagrams and the simplified influence diagrams that served as a roadmap for the necessary probability assessments.

A pilot test workshop took place at Stanford University in October of 1994, where a team of experts met to test and revise the initial risk assessment framework and provide preliminary probability data. Phil Beccue, Pete Morris, and Katherine Weller from ADA acted as facilitators. The participants were Bob Bidwell, John Boatwright, Steve Brown, Ken Haley, Hill Huntington, Michael May, Ed Porter, Mark Rodekohr, Harry Rowen, Dennis Taillie, and John Weyant.

The results of this prior assessment are summarized in the two probability distributions shown in Figure 12. It is interesting to note both the similarities and differences between the workshop results in 1994 (Figure 12) and the results from the most recent workshop in 1996 (Figure 9). First, both probability distributions show some probability greater than 50% that zero disruptions will occur over the 10-year period. We can also conclude that the likelihood of disruptions greater than 20% of world production is less than 1% for each workshop. These similarities result from applying a very similar framework (compare the October 1994 influence diagram in Figure 13 to the November 1996 influence diagram in Figure 8) and from common opinions about event probabilities.

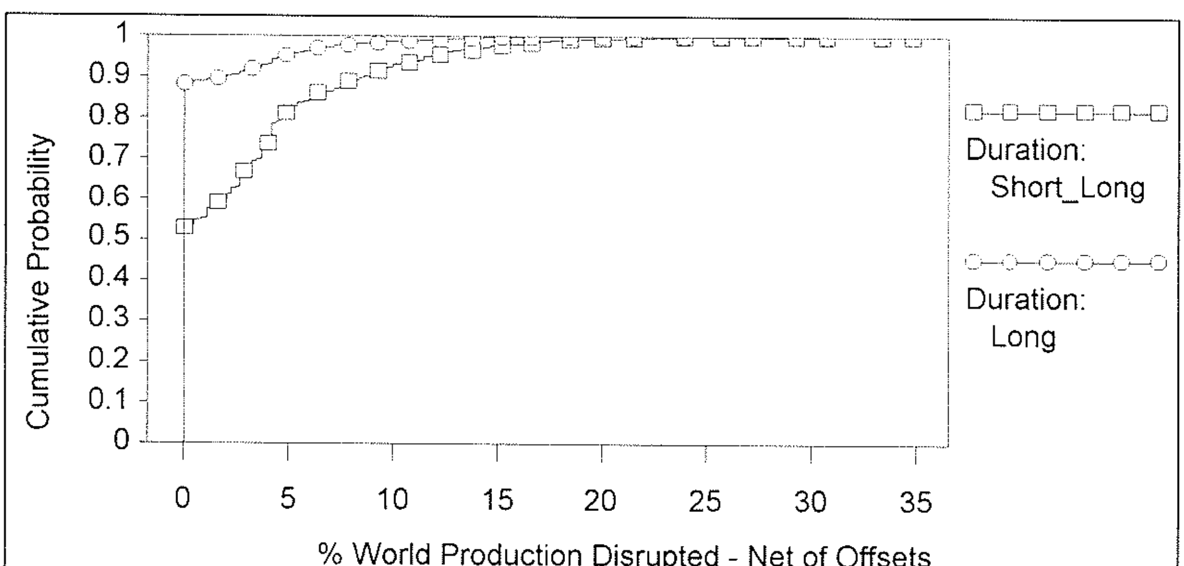

Figure 12. Risk Assessment Results from 1994 Pilot Test.

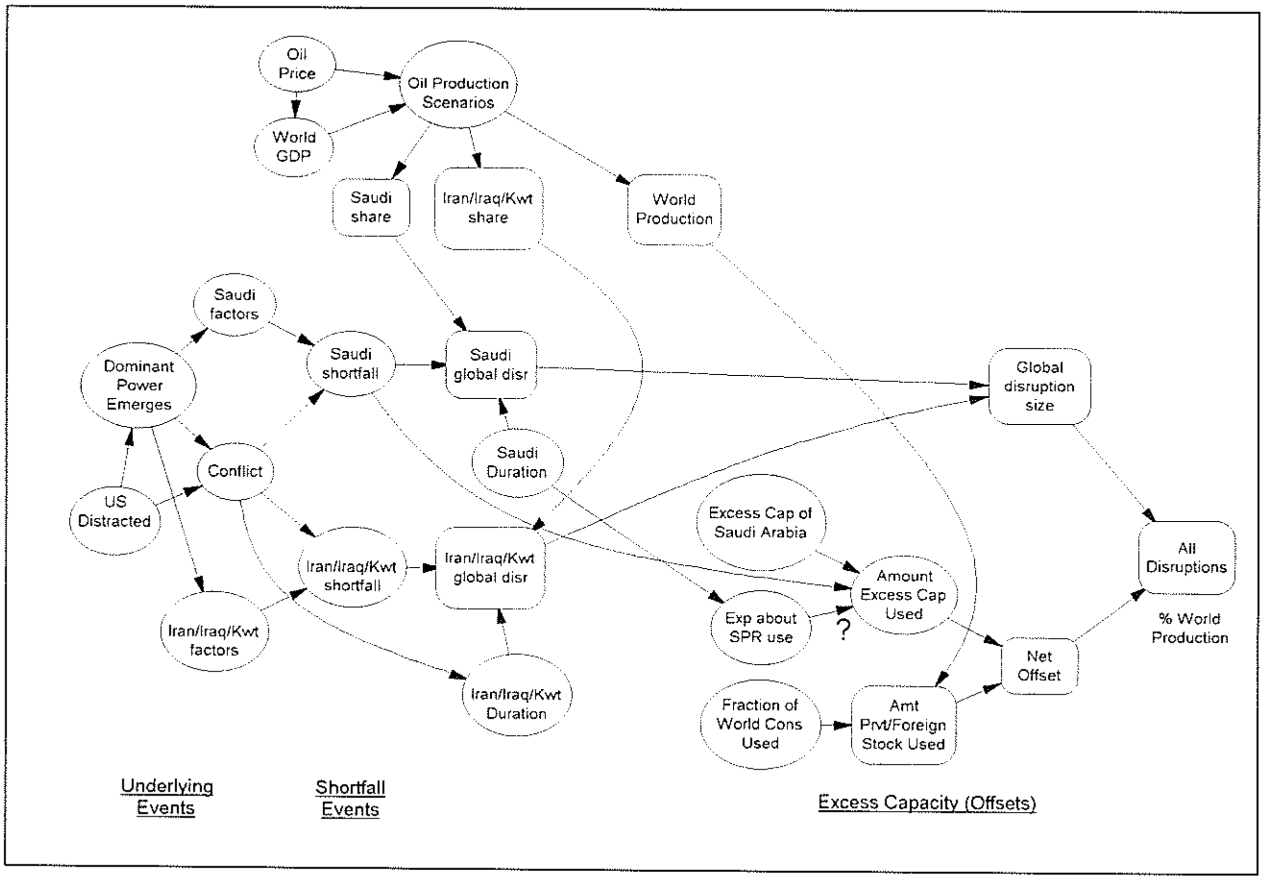

Figure 13. Influence Diagram from 1994 Pilot Test

In contrast, there are a number of clear differences in the results of the two workshops. A new group of experts and a changing world political scene prompted minor modifications to the influence diagram. For example, the reader will notice that the underlying events leading to Saudi and Iran/Iraq/Kuwait shortfall have been adjusted to reflect today's political climate. A new group of experts brought updated opinions about the likelihood of various events in the model. The new probability assessments resulted in changes to the resulting probability distribution on percent world production disrupted.

By carefully examining the probability distributions from 1994 (Figure 12) and 1996 (Figure 9), we can observe two differences from the shapes of the curves. First, the results from 1996 show a flat portion between 0% and 3% of world production, implying that there is little chance that we will experience small disruptions of this size. The reason for this conclusion is that the oil production scenarios for the most recent assessment were much different than the scenarios used in the earlier assessment. For example, 5-year forecasts for world oil production varied from 63 - 83 MMBD in 1994, whereas the same input for 1996 had a range of 78 - 83 MMBD. The wider variance in the earlier assessments resulted in the smaller disruption sizes that are not present in the 1996 assessment. Second, the probability of disruptions of long duration (greater than 6 months) is 12% in the 1994 pilot test, whereas it increased to 30% in the recent assessment. This is shown in the height of the vertical line for long disruptions at 0% disrupted.

much different view of the disruption duration. The combined assessments for duration are summarized in Table 1.

Table 1. Likelihood of disruption duration greater than six months

	1994	1996
Saudi	10%	38%
Iran/Iraq/Kuwait	18%	46%

Even though the chance of long duration disruptions has increased, the chance of all disruptions (short and long duration) is comparable between the two assessments (53% in 1994, 57% in 1996). In general, the differences between the 1994 and 1996 assessments can be explained by either refined assessments and/or updated beliefs on world politics and economics.

CONCLUSIONS

The feedback obtained from the panel of experts indicates their confidence in the capability of the decision and risk analysis techniques to accurately capture magnitude and duration of major oil disruption risks. The risk assessment methodology presented is a useful approach to uncover probabilistic information, and it is preferred over scenario analysis which ignores uncertainty.

Based on the experts' ability to work within the framework that was presented to them, the methodology is an appropriate tool to quantify issues surrounding energy security risks. The level of model detail appropriately captures the major dynamics and issues surrounding oil security, while requiring a manageable amount of data assessments and model run-time. As a whole, the panel felt that it is more important to have a well-defined framework and to structure the key influencing factors well, than to overemphasize the assessment of probability inputs.

The setting of expert workshops is an effective way to ensure the appropriateness of the framework. Collective judgment from a variety of experts is important to ensure that the results of probability assessments can be agreed upon by experts from diverse backgrounds.

SUGGESTIONS FOR FURTHER PROCEEDINGS

The 2-day energy security workshop in November 1996 was successful in verifying the risk assessment framework and updating the inputs to reflect current conditions. The quantification of the risks of oil disruptions opens the door to a variety of extensions of the framework. For example, the rigorous and proven standards of decision analysis reflect its suitability for use in policy decisions. The framework could be extended to analyze strategic decisions including stockpile releases and other types of decisions that could mitigate the impacts of oil disruptions.

One important theme in the feedback provided by the experts concerned the lack of diversity among the group. Specifically, they felt that the quality of the assessments could be improved by inviting participants from industry, as well as those with particular expertise in middle east politics and energy security. In future workshops, we recommend additional allocation of time to conduct the assessments. This is based on our experience in performing formal probability assessments, and confirmed by the experts at our workshop. Specifically, we recommend two separate meetings with at least 2 days (or more) between meetings to organize results and make the best use of the expert's time at the second meeting.

At the first meeting, 1-2 days will be required to refine and achieve buy-in to the framework, which includes a careful definition of events and event states, as well as the conditioning logic among events. This is best accomplished in a group setting with diverse backgrounds and opinions contributing to ensure that all issues are captured. The collective judgment of diverse experts is important to avoid bias in the results. The second meeting can be performed with smaller groups that consist of specialists in a particular area, much like in past workshops. The smaller groups can be conducted at different times or in different locations to suit the experts. These groups must agree on the framework as developed in the first set of meetings, and focus their attention on the probability inputs to the model. Although not as valuable as face-to-face interactions, it may be possible to encourage "higher-level" experts with stricter time constraints to participate through the use of formal scoring forms, video-conferencing, computerized interaction, or other technology aids.

APPENDIX A: PROBABILITY DATA

1a. U.S. Response Capability to Internal Crisis

100%	0.21
0%	0.79

1b. U.S. Response Capability to External Crisis

	U.S. Response to Internal Crisis	
	100%	0%
100%	1	0.75
0%	0	0.25

2. Potent Power Emerges

U.S. Response to External Crisis	U.S. Response to Internal Crisis	
	100%	0%
100%	0.21	0.77
0%	not real	0.90

3. Conflict

Potent Power Emerges	YES

	SCENARIO		
	X	Y	Z
Neutral	0.60	0.30	0.10
Big Iran/Iraq	0.20	0.40	0.40
Big Player	0.15	0.25	0.40
Other major	0.05	0.05	0.10

Potent Power Emerges	NO

	SCENARIO		
	X	Y	Z
Neutral	0.90	0.70	0.45
Big Iran/Iraq	0.05	0.15	0.225
Big Player	0.05	0.15	0.225
Other major	0	0	0.10

Scenario X = 100% effective response to external and internal crises
Scenario Y = 100% effective response to external crises but 0% effective response to internal crises
Scenario Z = 0% effective response to external and internal crises

4. Saudi Factors

Status Quo	0.60
More Severe Internal Problems	0.30
Intentional Reduction	0.10

5. Saudi Shortfall

Conflict: Neutral

Saudi Factors:		SQ	Internal Prob	Intent. Reductn
None	**(0%)**	0.97	0.80	0.85
Small	**(33%)**	0.02	0.15	0.15
Large	**(75%)**	0.01	0.04	0
All	**(100%)**	0	0.01	0

Conflict: Big Iran/Iraq

Saudi Factors:		SQ	Internal Prob	Intent. Reductn
None	**(0%)**	0.98	0.75	0.85
Small	**(33%)**	0.01	0.20	0.15
Large	**(75%)**	0.01	0.04	0
All	**(100%)**	0	0.01	0

Conflict: Big Player

Saudi Factors:		SQ	Internal Prob	Intent. Reductn
None	**(0%)**	0.20	0.10	0.95
Small	**(33%)**	0.60	0.40	0.03
Large	**(75%)**	0.15	0.30	0.02
All	**(100%)**	0.05	0.20	0

Conflict: Other Major

Saudi Factors:		SQ	Internal Prob	Intent. Reductn
None	**(0%)**	0.97	0.78	0.85
Small	**(33%)**	0.02	0.17	0.15
Large	**(75%)**	0.01	0.04	0
All	**(100%)**	0	0.01	0

6. Saudi Duration

	No War	War w/ Saudi
(<= 6 mos.)	0.75	0.25
(> 6 mos.)	0.25	0.75

7. Iran/Iraq/Kuwait (I/I/K) Factors

	Potent Power Emerges	
	Yes	No
Status Quo	0.30	0.20
More Severe Internal Problems	0.67	0.80
Intentional Reduction	0.03	0

8. Iran/Iraq/Kuwait Shortfall

Conflict: Neutral

IIK Factors:		Stable	Social Prob	Intent. Reductn
None	(0%)	0.98	0.80	0.50
Small	(33%)	0.02	0.20	0.50
Large	(75%)	0	0	0
All	(100%)	0	0	0

Conflict: Big Iran/Iraq

IIK Factors:		Stable	Social Prob	Intent. Reductn
None	(0%)	0.25	0.25	0.25
Small	(33%)	0.65	0.65	0.65
Large	(75%)	0.10	0.10	0.10
All	(100%)	0	0	0

Conflict: Big Player

IIK Factors:		SQ	Internal Prob	Intent. Reductn
None	(0%)	0	0	0
Small	(33%)	0.25	0.20	0.20
Large	(75%)	0.50	0.55	0.55
All	(100%)	0.25	0.25	0.25

Conflict: Other Major

IIK Factors:		SQ	Internal Prob	Intent. Reductn
None	(0%)	0.85	0.70	0.10
Small	(33%)	0.10	0.20	0.85
Large	(75%)	0.05	0.10	0.05
All	(100%)	0	0	0

9. Iran/Iraq/Kuwait Duration

	Conflict			
	Neutral	Big Iran/Iraq	Big Player	Other Major
Short (<= 6 mos.)	0.95	0.2	0.25	0.2
Long (> 6 mos.)	0.05	0.8	0.75	0.8

10a. Saudi Expectations About SPR Use

	Iran/Iraq/Kuwait Duration	
	Short	Long
Expect	0.25	0.50
Don't Expect	0.75	0.50

10b. I/I/K Expectations About SPR Use

	Saudi Duration	
	Short	Long
Expect	0.40	0.85
Don't Expect	0.60	0.15

11a. Excess Capacity from Saudi Available

	MMBD	Probability
Low	0	0.05
Med	2.5	0.80
High	4.0	0.15

11b. Excess Capacity from I/I/K Available

	MMBD	Probability
Low	0	0.05
Med	0.5	0.80
High	1.0	0.15

12a. Amount of Saudi Excess Capacity Used

	I/I/K Shortfall			
	None (0%)	Small (33%)	Large (75%)	All (100%)
Use None	1	0.20	0.10	0.05
Use Half	0	0.75	0.55	0.30
Use All	0	0.05	0.35	0.65

12b. Amount of I/I/K Excess Capacity Used

	Saudi Shortfall: None (0%)	Small (33%)	Large (75%)	All (100%)
Use None	1	0.10	0.10	0.10
Use Half	0	0.40	0.40	0.40
Use All	0	0.50	0.50	0.50

13. Amount of Private/Foreign Stock Used

	Probability	% World Consumption
Low	0.15	0
Med	0.60	0
High	0.25	2.5

14. Oil Production Scenarios

Saudi Arabia

	Probability	2000 Price	2000 MMBD	2005 Price	2005 MMBD	2010 Price	2010 MMBD
High Q	0.20	$13.50	12.5	$14.00	13.5	$14.50	14.6
Middle Q	0.50	$19.00	11.5	$21.50	12.8	$24.00	14.1
Low Q	0.30	$21.00	10.8	$24.50	11.5	$30.00	12.3

Iran/Iraq/Kuwait

	Probability	2000 Price	2000 MMBD	2005 Price	2005 MMBD	2010 Price	2010 MMBD
High Q	0.20	$13.50	13.0	$14.00	15.3	$14.50	16.9
Middle Q	0.50	$19.00	11.6	$21.50	14.0	$24.00	16.0
Low Q	0.30	$21.00	11.0	$24.50	12.2	$30.00	13.9

Total World

	Probability	2000 Price	2000 MMBD	2005 Price	2005 MMBD	2010 Price	2010 MMBD
High Q	0.20	$13.50	79.1	$14.00	87.7	$14.50	94.5
Middle Q	0.50	$19.00	76.3	$21.50	82.9	$24.00	88.4
Low Q	0.30	$21.00	75.5	$24.50	81.9	$30.00	84.5