An Assessment of Oil Market Disruption Risks

FINAL REPORT
EMF SR 8

October 3, 2005

Prepared by:

Phillip C. Beccue

Hillard G. Huntington
Energy Modeling Forum
Stanford University
Stanford, CA 94305-4026

Prepared For
U.S. Department of Energy
Washington, D.C. 20036

Acknowledgements and Disclaimers

This report was prepared by Philip Beccue, a consultant to the Energy Modeling Forum, and Hillard Huntington of the Energy Modeling Forum for work sponsored by the U.S. Department of Energy. The views and conclusions expressed in this report are the authors' and do not reflect opinions or positions of the U.S. Department of Energy or any workshop participants or their organizations. We are particularly indebted to the participants in our oil security workshops for their valuable inputs during the study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SECTION 1. EXECUTIVE SUMMARY

The probability of the size and duration of another oil disruption is critical to the estimated value of the strategic petroleum reserve (SPR) and its desired size. Recent changes in world events (war in Iraq and Afghanistan), tensions in other parts of the world and energy markets (oil price increases), along with President Bush's 2001 directive to the Department of Energy (DOE) to fill the SPR to its capacity of 700 million barrels to "maximize long-term protection against oil supply disruptions" have renewed interest by the DOE and other parties in understanding the risk of major oil disruptions.

The Energy Modeling Forum at Stanford University developed a risk assessment framework and evaluated the likelihood of at least one foreign oil disruption over the next ten years. Although it was recognized that domestic and weather-related oil disruptions could also be very damaging, we were asked to focus the effort specifically upon geopolitical, military and terrorist causes for disruptions overseas. A broader study of all sources for future disruptions would have required an assessment of more experts, which would not have been possible given the resources available for the project.

The risk assessment was conducted through a series of workshops attended by leading geopolitical, military and oil-market experts who provided their expertise on the probability of different events occurring, and their corresponding link to major disruptions in key oil market regions. Special attention was made to differentiate disruptions by their magnitude, by their likelihood of occurrence, and by whether they are short-, long-, or very long-term in duration.

The final results of the risk assessment convey a range of insights across the three dimensions of magnitude, likelihood, and length of a disruption. These conclusions are net of offsets, with the notable exception that the SPR is not included as a source of offsets. At least once during the 10-year timeframe 2005-2014:

- The probability of a net (of offsets) disruption of 2 MMBD (million barrels per day) or more lasting at least <u>1 month</u> is approximately 80%.
- The probability of a net (of offsets) disruption of 2 MMBD or more lasting at least <u>6 months</u> is approximately 70%.
- The probability of a net (of offsets) disruption of 2 MMBD or more lasting at least <u>18 months</u> is approximately 35%.
- The chance of a 3 MMBD net disruption or more lasting at least 1 month is 65%; the chance of 5 MMBD or more is about 50%.
- There is a greater probability for any disruption lasting >1 month in the Other Persian Gulf region (83%) comprised of Iran, Iraq, Kuwait, Qatar, UAE and Oman, or the West of Suez region (72%) comprised of Algeria, Angola, Libya, Mexico, Nigeria and Venezuela, than in Saudi Arabia (49%).
- There is a lesser probability for any disruption lasting >1 month in Russia and the Caspian States (17%) than in Saudi Arabia (49%).
- The chance of 5 MMBD disruption size (or greater) is 60% for active war in the Middle East, 34% for no conflict in the Middle East, and 47% assuming base case assumptions.

Offsets from the use of excess capacity outside the disrupted region reduce the size of the disruption. We conclude that offsets reduce the probability that the net disruption reaches any given size by approximately 5%-15%. Finally, bigger disruptions (as measured in MMBD) last longer (number of months) than smaller disruptions.

A similar risk assessment was conducted by the EMF in 1996. The current assessment covers four regions of the world instead of two regions, has updated probabilities to reflect current world conditions, and has modified excess capacity and oil supply forecasts. The net effect of these changes shows an increased likelihood of disruptions for all sizes up to 10 MMBD, but the same estimate as 1996 for disruption sizes of greater than 10 MMBD (7-8% or lower).

The structured framework based on decision and risk analysis techniques provided an efficient method to quantify the complexity surrounding oil disruption scenarios in a transparent and traceable logic. The risk assessment also provided a systematic framework for supporting these estimates, and has demonstrated an approach that can be updated as future world events change.

SECTION 2. MOTIVATION

The probability of another oil disruption is critical to the estimated value of the strategic petroleum reserve (SPR) and its desired size. And yet, various estimates of the risk of comparable disruptions during the 1990s varied by as much as a factor of five (Leiby and Bowman, 2003). This disparity in results reflects that analysts use fundamentally different approaches and assumptions. An additional problem is that there is no consistency in developing these estimates over time. Estimates that change over time should reflect shifts in actual conditions influencing the true probability of a disruption rather than who conducts the study and with which approach.

There are currently no reliable estimates of the risks of another oil disruption. As a result, policymakers have only broad perceptions of how recent events have changed probabilities. Responsible policymaking requires more quantitative and thoughtful evaluations of these important risks even though many of the events considered have never occurred in the last 30 years.

Due to these factors, the Stanford Energy Modeling Forum set out to accomplish three objectives:

- Develop a risk assessment framework and utilize expert judgment to develop the overall probability of a major oil disruption
- Characterize the likelihood, effective magnitude, and duration of potential supply disruptions
- Clearly document the logic and assumptions driving the risk analyses.

Before discussing the detailed results of the risk assessment, we begin by describing the approach and review the key inputs developed by the experts.

SECTION 3. APPROACH

Formal probabilistic risk assessments have been widely used to analyze a range of topics where:

- uncertainty is paramount
- many interrelated factors cause significant complexity
- information is available from many sources
- policymakers want a quantitative, logical, and defensible analysis of the associated risks.

The most detailed, thorough and structured approach for evaluating these risks lies in elicitation of the views of an expert panel, such as that previously conducted by the Stanford Energy Modeling Forum in 1996 (Huntington, Weyant, Kann and Beccue, 1997). This approach, drawing on the tools and principles of decision analysis, is based upon structured modeling where specific events are identified and their probabilities are evaluated. The approach allows interdependencies to exist between events, thereby providing a richer evaluation of the underlying risks of disruptions. The assessment incorporates expert judgment to provide an explicit quantification of the magnitude, duration and likelihood of oil supply events that could cause significant upward deviations in world oil prices.

Expert evaluation requires considerable experience in appropriate techniques for uncovering unbiased responses from workshop participants. To facilitate the assessment, we conducted the following steps:

1. Brainstorm factors
2. Categorize into regional vs. broader underlying events (which impact multiple regions)
3. Develop influence diagrams to identify the relationships between events
4. Develop scales for each event to define two or more states
5. Assign likelihoods for each state
6. Combine mathematically by analyzing all combination of outcomes and weighting them according to probability inputs from experts.

PARTICIPANTS

Phil Beccue and Deanna Przybyla, decision analysis facilitators, and Hill Huntington from the Energy Modeling Forum, Stanford University, conducted a series of three workshops. The workshops took place in the Washington, D.C. area in December 2004, February 2005, and July 2005. 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 are recorded in Table 1.

Table 1. Participants in the 2005 Oil Risk Assessment

Kenneth Austin	U.S. Treasury Department
Phil Beccue	Independent Consultant
Jerry Berndsen	U.S. Department of Energy
Tara Billingsley	Office of Intelligence- DOE
Edward C. Chow	**Consultant**
Ted Chu	General Motors Corporation
Patrick Clawson	**The Washington Institute for Near East Policy**
Michael Cohen	U.S. Department of Energy
Glenn H. Coplon	U.S. Department of Homeland Security
Terry Coyne	Central Intelligence Agency
Jeremy Cusimano	U.S. Department of Energy
Robert Ebel	**Center for Strategic & Intl Studies**
Charles Esser	U.S. Department of Energy
Lowell Feld	U.S. Department of Energy
Mark Finley	BP America, Inc.
Hillard Huntington	Stanford University
Amy Myers Jaffe	**Rice University**

David Johnson	U.S. Department of Energy
Richard Karp	**American Petroleum Institute**
Nasir Khilji	U.S. Department of Energy
Lori Krauss	Office of Management & Budget
Paul Leiby	Oak Ridge National Laboratory
Lynette Lemat	U.S. Department of Energy
Edward Porter	American Petroleum Institute
Deanna Przybyla	Consultant
Mark Rodekohr	U.S. Department of Energy
John D. Shages	U.S. Department of Energy
Thomas Sperl	U.S. Department of Energy
Frank Verrastro	**Center for Strategic & Intl Studies**
Michael Whinihan	General Motors Corporation

BOLD: **country experts**
Red: Sponsors

The workshops focused on incorporating expert judgment in the explicit quantification of the magnitude and likelihood of oil disruptions. To start off the assessment workshop, all participants provided estimates for Saudi factors. The participants were then divided into three groups: Other Persian Gulf, West of Suez, and Russian and Caspian States. At the end of the day, the group came together and finished with an assessment of offsets and duration probabilities.

SECTION 4. SCOPE

SHORTFALL DEFINITION

For the oil risk assessment, a disruption or shortfall is defined as:

> "A sudden shortfall in oil production from a world supplier that results in at least 2 MMBD unavailable within 1 month of the beginning of the disruption. After the period, world production recovers to the same level prior to the shortfall. The disruption occurs at least one time during the 10-yr period 2005-2014."

This definition provides an explicit event for experts to evaluate the probability of an oil disruption. A shortfall is not defined as a movement in prices.

Major world oil supply regions include: (1) Saudi Arabia, (2) Other Persian Gulf countries, (3) West of Suez, and (4) Russia and Caspian states. We focused on these four oil supply regions and treated each set of countries within a region as a group. The Other Persian Gulf and West of Suez countries include:

Other Persian Gulf	West of Suez
Iran	Algeria
Iraq	Angola
Kuwait	Libya
Qatar	Mexico
UAE	Nigeria
Oman.	Venezuela

The production capacity from the IEO Reference Case for 2010 for each region is:

- Saudi 13.2 MMBD
- Other Persian Gulf 14.7 MMBD
- West of Suez 15.7 MMBD
- Russia & Caspian 13.2 MMBD

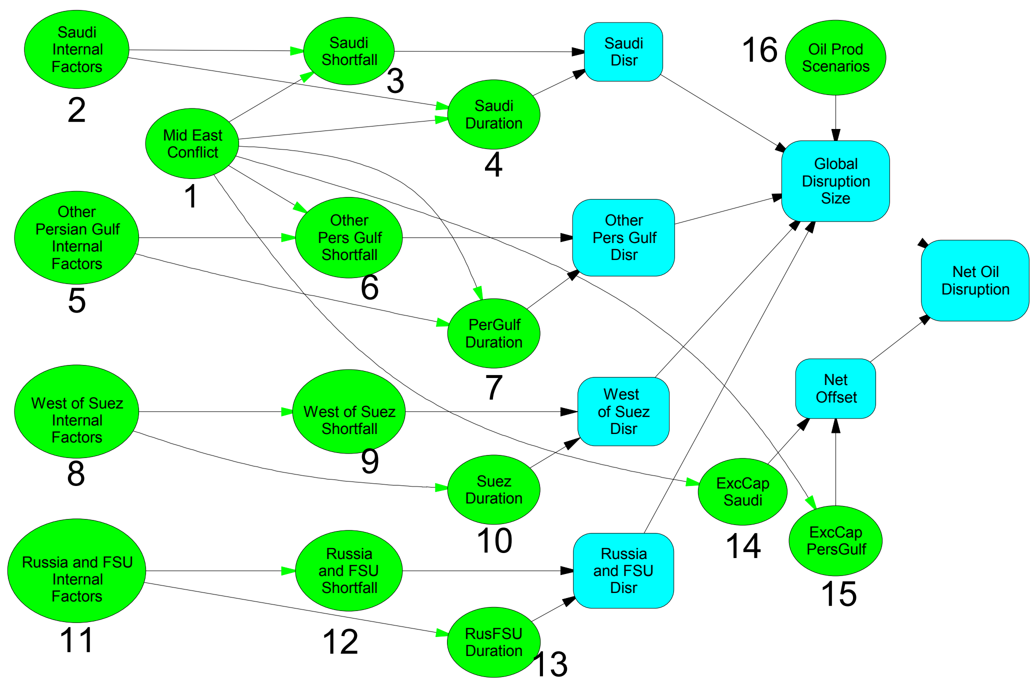
Major offsets to the gross disruptions consist of excess capacity carried by Saudi Arabia, as well as Other Persian Gulf sources.

The initial risk assessment framework was developed in an initial structuring meeting with energy security experts in December 2004. 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.

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 and refinement of the December 2004 workshop participants is shown in Figure 1.

Figure 1. World Oil Disruption Influence Diagram.



The rounded rectangles represent calculated quantities, while the ovals represent uncertain variables. This diagram captures the primary events that could lead to major world oil disruptions in a form conducive to data input and analysis. The sixteen numbered ovals represent the parameters requiring probability assessments. 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. The primary underlying event, Middle East Conflict, impacts shortfalls in two dominant regions (Saudi Arabia and Other Persian Gulf). Net oil disruptions are calculated by summing global disruption size and subtracting net offsets (if offsets are available).

Each of the uncertain variables (ovals on the influence diagram) requires probability assessments from experts. Before assessing probability estimates, it is very important to have a clear definition of each variable. A scale with two or more discrete levels measures the variables. The experts developed the scales during the structuring meeting by identifying discrete levels for each parameter that were both non-overlapping and spanned the set of possibilities. Care was taken by the experts to review the variable definitions and associated scales before providing probability assessments. The event definitions and scales are summarized in the next section and shown in detail in Appendix B.

SECTION 5. EXPERT ASSESSMENTS

Developing the simplified influence diagram was an efficient method to reduce a highly complex risk assessment task into a manageable exercise. With the influence diagram structure as a guide, the group of experts developed carefully worded scale definitions for each variable, and, through a group probability assessment exercise, achieved a consensus view on the probability appropriate for each level of the scale. The risk assessment required scale definitions and probability assessments on six variable types: global underlying events, regional factors, regional shortfall, regional duration, future oil production, and excess capacity. These inputs will be discussed in the next sections, starting with global underlying events and regional factors in one category labeled "conditioning events."

CONDITIONING EVENT SCALES AND PROBABILITIES

The influence diagram of Figure 1 contains one global underlying event (Middle East Conflict) and four regional factors corresponding to the internal affairs of each of the four regions. These five parameters are defined as independent variables in that they are estimated independent of the states of any other variables. The notion of independence is reflected in the influence diagram by the lack of any conditioning arrows pointing to these nodes. The scale definitions and probability assessments are in Tables 2-6.

SHORTFALL SCALES AND PROBABILITIES

The amount of disruption of supply in each region could range from none to a complete disruption. Although the amount of shortfall is a continuous variable, we approximated it as a discrete variable with four states, expressed as a fraction of that region's supply:

No shortfall	0 - 10% of supply
Small shortfall:	>10 - 30% of supply
Medium shortfall:	>30 - 80% of supply
All:	>80% of supply

The total supply for each region was taken from the EIA's 2004-IEO forecast (see below). For simplicity, the assumptions used in the analysis for "percent of supply lost" is 0%, 20%, 50%, and 90% corresponding to the four shortfall regions above.

Table 2. Middle East Conflict Scale and Probability Assignments

5%	1. No conflict (any existing conflict ending quickly)
50%	2. Limited war, including active insurgent operations, e.g., Arab/Iran - Israeli War
15%	3. Spillover from one producer to chaos or unrest in other producers (not including Saudi)
20%	4. Limited active war between oil producers and possibly U.S.(limited in time and scope); e.g., also could include UN sanctions instead of war
10%	5. Extended active war in time and scope (e.g., among 1 or more producing countries with the involvement of the US and possibly Israel, unsettled conditions and internal strife and an Israeli/Arab armed conflict)

Table 3. Saudi Internal Factors

Alternate Opinion		
20%	40%	1. Stable internal affairs with *no* voluntary Saudi cutback
30%	10%	2. Stable internal affairs *with* voluntary Saudi cutback to maintain price target (this event is a voluntary cut back in an otherwise tight market; excludes the case of OPEC quotas which are designed to handle excess capacity problems; "oil weapon" case)
	30%	3. Low level insurgency, intermittent oil disruptions
	15%	4. Saudi gov't hostile to the West, continuing turmoil/tension which causes most skilled workers to leave; Saudi gov't not able to attract new workers; insurgency makes them feel unsafe; gov't is hostile to them
	5%	5. Civil war or potential failed state

Table 4. Other Persian Gulf Internal Factors

If No Saudi Cutback	If Saudi cutback or turmoil	
32%	18%	1. Stable internal affairs except Iraq with *no* voluntary Other Persian Gulf cutback
4%	18%	2. Stable internal affairs except Iraq *with* voluntary Other Persian Gulf cutback
	50%	3. Civil war or prolonged succession in 1 major producer, e.g., Iraq/Iran
	14%	4. Simultaneous civil war or prolonged succession turmoil in 2 or more major producers

Table 5. West of Suez Internal Factors

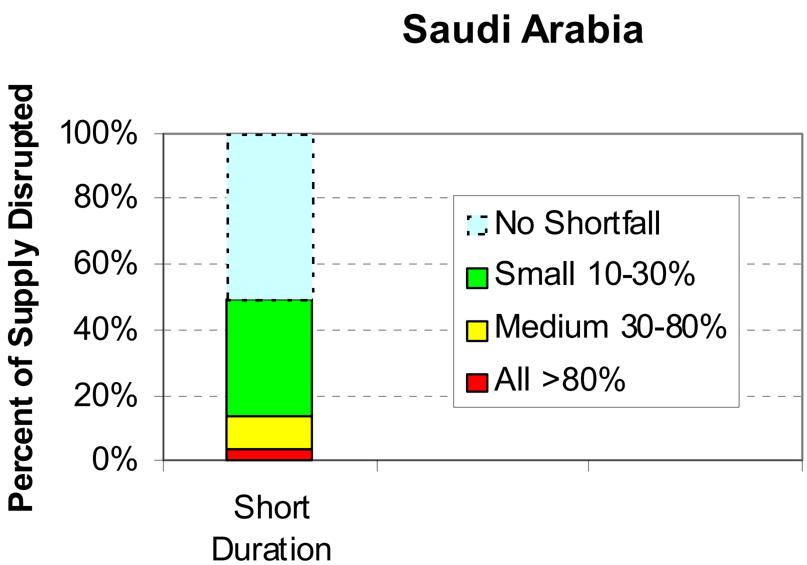
Active war in mid east	No active war in mid east	
8%	10%	1. Stable internal affairs with *no* voluntary West of Suez cutback
2%	0%	2. Stable internal affairs *with* voluntary West of Suez cutback
	50%	3. Civil war or labor disputes in 1 major producer
	25%	4. Extended civil war, terrorist attack or turmoil in 2 or more major producers
	15%	5. Failed state in one of the major producers and labor unrest in another producer

Table 6. Russian and Caspian States Internal Factors

Active war in mid east	No active war in mid east	
70%	60%	1. Stable internal affairs with *no* voluntary Russia & Caspian States cutback
0%	10%	2. Stable internal affairs *with* voluntary Russia & Caspian States cutback
	20%	3. Terrorist attacks on oil facilities
	10%	4. Prolonged ethnic insurgency in a major producing or transit region; or major border conflict among major producers

Estimating the probabilities for the shortfall scale in each region is more complicated than the regional factors due to their conditioning events (see the influence diagram of Figure 1). For example, the Saudi Shortfall variable has two arrows leading into it from Middle East Conflict and Saudi Internal Factors. The Saudi Shortfall uncertainty requires multiple assessments, one for each combination of conditioning event states. The details of the expert's assessment can be found in Appendix C. A summary of the shortfall, combining the individual conditioned assessments and the weighting of the underlying events, is shown in Figure 2.

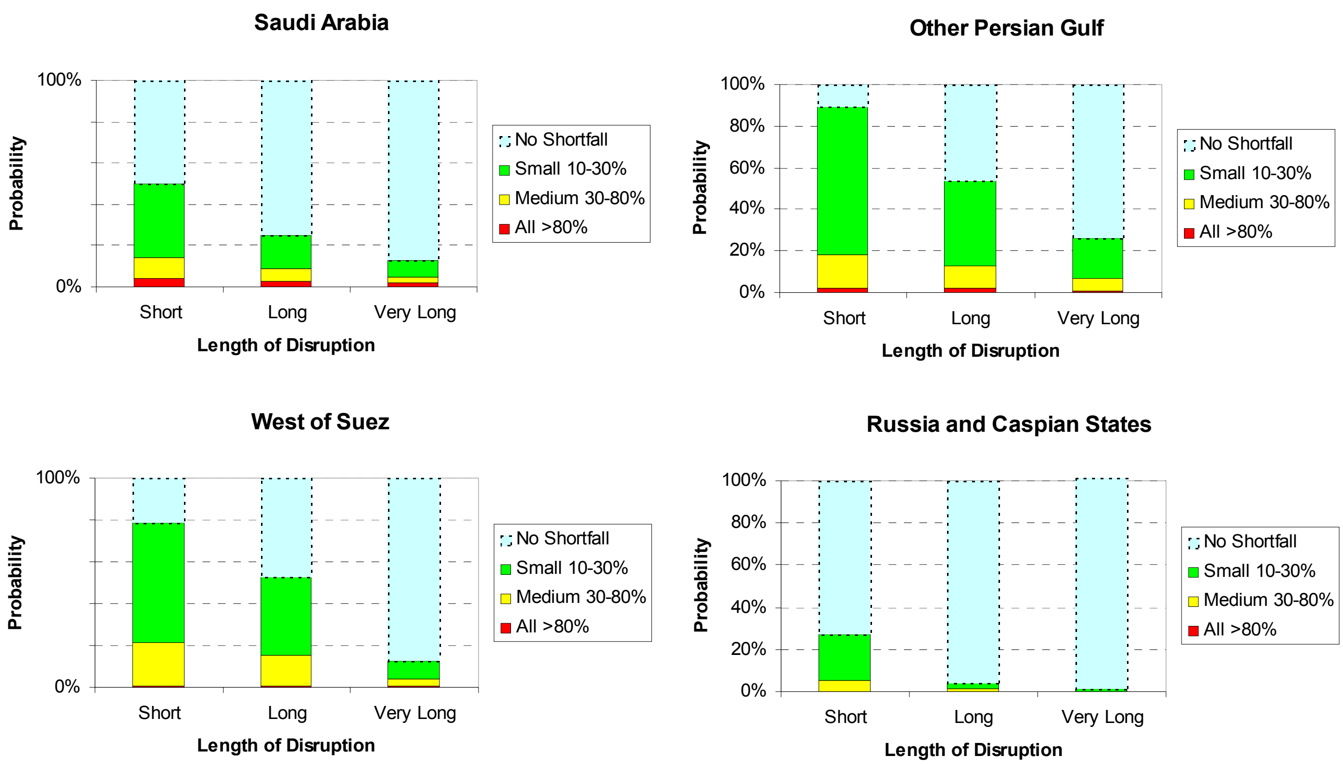
Figure 2. Percent of Supply Disrupted in Saudi Arabia



For short disruptions in Saudi, the experts concluded that there is a 50% chance that no disruption will occur (taking all factors into account, including Saudi Internal Affairs and Middle East Conflict). Furthermore, the chance of a disruption of 10-30% of capacity is 35%, the chance of a medium-sized disruption (30-80% of capacity) is 10%, and the chance of a complete disruption of Saudi capacity is 5%.

Similar to the Saudi region, the probabilities assigned to the shortfall amount in the other three regions are also conditioned assessments, and their inputs are in Appendix C. Figure 3 summarizes the shortfall estimates for all four regions and each duration. The Russian and Caspian States region has the lowest likelihood of supply disruption, while the Other Persian Gulf region has the highest likelihood (90% chance of a small or medium amount for short durations), followed by West of Suez and Saudi Arabia.

Figure 3. Percent of Supply Disrupted in All Regions



DURATION SCALES AND PROBABILITIES

Disruptions are defined to last a minimum of one month before supply is resumed. Once a disruption has occurred, it could either be classified as a short-duration disruption wherein supplies are restored within six months, a long-duration disruption that lasts between 6-18 months, or a very long-duration disruption lasting from 18-36 months. By our definition, all disruptions are in the short-duration category, since long-duration disruptions were at one time a short disruption. However, a subset of disruptions falls into the long-duration category, and a subset of these fall into the very long-duration category. The experts were asked to identify the probability of a disruption being restored within six months, within 18 months, or beyond 18 months. The answer to this question depends on internal factors in that region and (possibly) on factors throughout the Middle East. Figure 4 identifies 25 possible states that reflect these interrelationships for Saudi, and 20 states for Other Persian Gulf.

Figure 4. Group Assignments for Saudi Duration and Other Persian Gulf

Saudi Internal Factors

Middle East Conflict	Stable - with no voluntary Saudi cutback	Stable - *with* voluntary Saudi cutback	Low-level insurgency - intermittent disruptions	Saudi govt hostile to West	Civil war or potential failed state
1. No conflict (any existing conflict ending quickly)	*Group A*	*Group A*	*Group A*	*Group C*	*Group C*
2. Limited war, including active insurgent operations, e.g., Arab/Iran - Israeli War	*Group A*	*Group A*	*Group B*	*Group C*	*Group C*
3. Spillover from one producer to chaos or unrest in other producers (not including Saudi)	*Group A*	*Group A*	*Group B*	*Group C*	*Group C*
4. Limited active war between oil producers and possibly U.S.(limited in time and scope); e.g., also could include UN sanctions instead of war	*Group B*	*Group B*	*Group B*	*Group C*	*Group C*
5. Extended active war in time and scope (e.g., among 1 or more producing countries with the involvement of the US and possibly Israel, unsettled conditions and internal strife and an Israeli/Arab armed conflict)	*Group B*	*Group B*	*Group C*	*Group C*	*Group C*

Other Persian Gulf Internal Factors

Middle East Conflict	Stable except Iraq with no voluntary Other PG cutback	Stable except Iraq *with* voluntary Other PG cutback	Civil war or succession in 1 major producer	Civil war or succession in 2 or more major producers
1. No conflict (any existing conflict ending quickly)	*Group A*	*Group A*	*Group A*	*Group C*
2. Limited war, including active insurgent operations, e.g., Arab/Iran - Israeli War	*Group A*	*Group A*	*Group B*	*Group C*
3. Spillover from one producer to chaos or unrest in other producers (not including Saudi)	*Group A*	*Group A*	*Group B*	*Group C*
4. Limited active war between oil producers and possibly U.S.(limited in time and scope); e.g., also could include UN sanctions instead of war	*Group B*	*Group B*	*Group B*	*Group C*
5. Extended active war in time and scope (e.g., among 1 or more producing countries with the involvement of the US and possibly Israel, unsettled conditions and internal strife and an Israeli/Arab armed conflict)	*Group B*	*Group B*	*Group C*	*Group C*

To simplify the assessment task for Saudi, the 25 distinct scenarios were classified into three groups, with each group being treated as having a similar likelihood of duration. Group A is characterized by mostly shorter disruptions, Group C by longer disruptions, and Group B by a mixture of short and long durations. Their probability assignments are shown in Figure 5.

Figure 5. Disruption Duration Probabilities for Saudi and Other Persian Gulf

SAUDI		Group A	Group B	Group C
Duration	Short (1-6mo)	80%	50%	20%
	Long (6-18mo)	15%	30%	20%
	Very Long (>18mo)	5%	20%	60%

OTHER PERSIAN GULF		Group A	Group B	Group C
Duration	Short (1-6mo)	80%	35%	10%
	Long (6-18mo)	15%	40%	25%
	Very Long (>18mo)	5%	25%	65%

EXCESS CAPACITY SCALES AND PROBABILILITES

If a disruption of oil supplies occurs, it may be offset completely or partially by excess capacity. The panel of experts agreed that significant excess capacity is only available from Saudi and Other Persian Gulf sources. Saudi excess capacity could be up to 5 MMBD (in 2005 it is estimated to be 0.5MMBD) and Other Persian Gulf up to 3 MMBD (in 2005 it is estimated to be about 0 MMBD). The experts provided estimates on likelihoods of various amounts available at the time of a disruption in Figure 6.

Excess capacity is only available to offset disruptions if the internal affairs in that region are stable. Furthermore, none would be available if that region was experiencing a disruption. Taking into account this logic, combined with the probability inputs in Figure 6, we can compute the probability distribution on excess capacity available (Figure 7). From all sources, we conclude that the average excess capacity available is 0.8 MMBD, and the chance that none will be available is just over a 55%.

Figure 6. Excess Capacity Amount and Likelihood

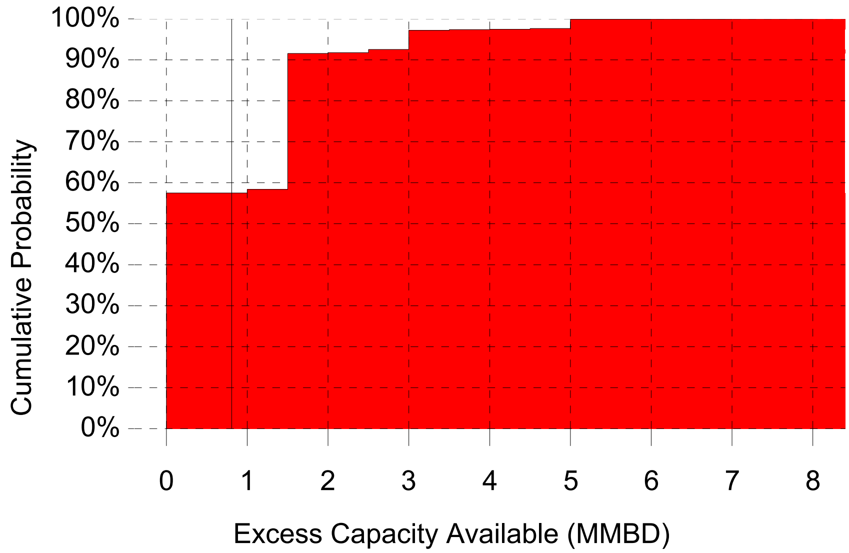
Saudi Excess Capacity

MMBD	Probability
0	10%
1.5	75%
3	10%
5	5%

Other Per Gulf Excess Capacity

MMBD	Probability
0	70%
1	20%
2	5%
3	5%

Figure 7. Probability Distribution of Net Excess Capacity Available



DISRUPTION SIZE AND OVERLAP

The dependencies between regions were captured with arrows on the influence diagram and subsequent assessments from experts. For example, assuming a major conflict in the Middle East, experts provided higher estimates for the probability of a shortfall in both Saudi and Other Persian Gulf. However, there are cases wherein a shortfall could occur in more than one region even without the conditioning event (e.g., internal conflict in one region, terror attack in another region). In this case the question arises, do these shortfalls occur simultaneously or at different times in the 10-yr horizon? Since either case could occur, we considered both cases in the scenario analyses. If the shortfalls occurred simultaneously, the disruption sizes were added together. However, if the shortfalls occurred at different times, then we assumed the largest of the shortfalls was relevant, and ignored the smaller sizes. The chosen methodology does not account for the number of times a shortfall occurs in the horizon.[1]

Approximations of the probability of an overlap of regional shortfalls, given that two or more regions experience a disruption, were derived analytically from assumptions that a shortfall is equally likely to occur at any time in the 10-yr window, along with shortfall length. Details of the approximations can be found in Appendix D. If a short duration disruption occurs in multiple regions, there is no overlap 66% of the time, overlap with 2 regions 29%, with three regions 4%, and overlap of all four regions less than 1%.

[1] Recall the definition of a shortfall is a disruption that occurs at least one time in the 10-yr horizon.

OIL PRODUCTION SCENARIOS AND PROBABILITIES

The size of a disruption is a function of the percent of supply lost in a region and the total supply for that region. Within the 10-yr risk assessment timeframe 2005-2014, we chose the year 2010 as representative year and considered three oil capacity scenarios from the Energy Information Administration's 2004 IEO forecast (Figure 8). The high, reference, and low price scenarios were assigned probabilities of 50%, 35%, and 15%, respectively.

Figure 8. Oil Production Scenarios

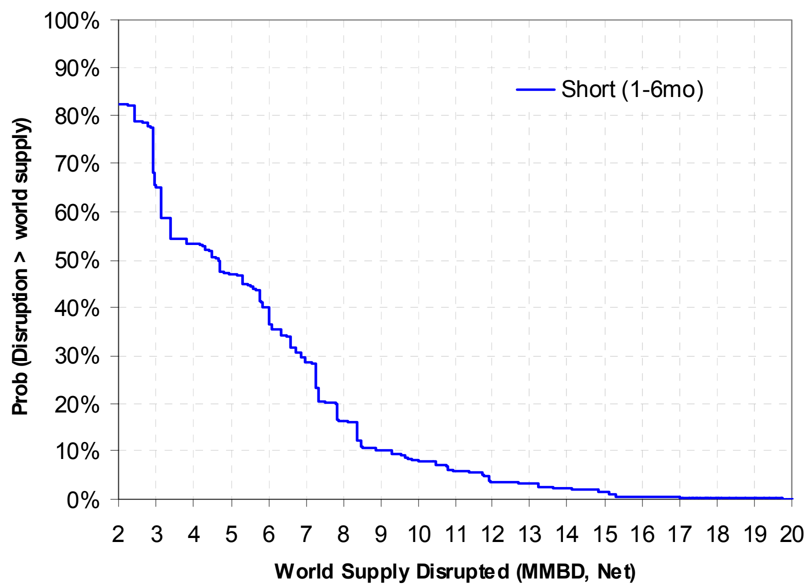
Oil Capacity (2010) from EIA's 2004-IEO

Country	High Price	Reference	Low Price
Iran	3.9%	4.2%	4.5%
Iraq	3.2%	3.9%	4.4%
Kuwait	2.6%	3.3%	3.6%
Saudi Arabia	10.4%	13.9%	16.7%
Total Persian Gulf	23.8%	29.3%	33.4%
Nigeria	2.4%	2.7%	3.0%
Venezuela	3.6%	3.9%	4.3%
Total Other OPEC	11.3%	12.4%	12.9%
Total OPEC	35.1%	41.7%	46.3%
Former Soviet Union	15.4%	13.9%	12.8%
United States	11.0%	10.0%	9.1%
Total Industrialized	28.4%	26.1%	23.9%
Total Non-OPEC	64.9%	58.3%	53.7%
Total World	100.0%	100.0%	100.0%
Levels			
Capacity (MMB/Day)	90	95.1	100.6
Price (2002$/B)	33.28	24.18	16.99
Probability	**50%**	**35%**	**15%**

SECTION 6. RESULTS

The detailed probability data obtained from the experts are listed in Appendix C. 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 (over 20 million scenarios) and weighted each scenario by its likelihood of occurrence.

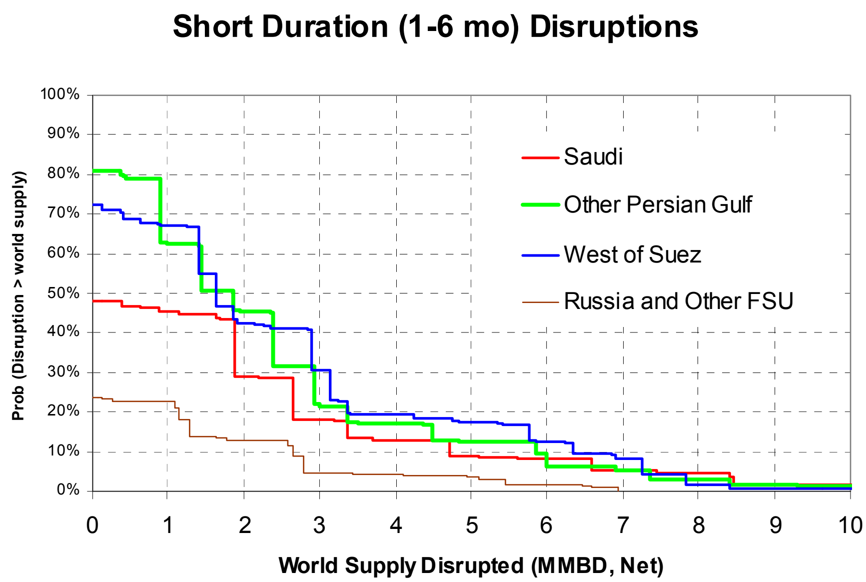
Figure 9. Probability of an Oil Disruption Lasting 1-6 Months



The scenario-probability pairs are succinctly summarized and displayed in an Excess Probability graph shown for all disruptions in Figure 9. The curve plots the probability that a disruption will occur in the next 10 years of at least x, for each value of x (in MMBD, net of offsets) on the horizontal axis. The graph focuses on magnitudes of 2 MMBD and greater, since small disruptions are less relevant for SPR planning purposes. For example, the data point at 5 MMBD and 45% can be described as a 45% chance that a 5 MMBD disruption or larger will occur at least one time in the 10-year timeframe 2005-2014. It is very likely that a disruption greater than 2 MMBD will occur (over 80%). However, it is unlikely that disruptions greater than 15 MMBD will occur (less than 1%). This curve allows one to easily identify the likelihood of disruption sizes within a range. For example, the probability of a disruption between 5-10 MMBD is 37% (probability of >5 is 45%, probability of >10 is 8%, difference is 45%-8% = 37%). The graph shows a larger weighting for 3 MMBD and 8 MMBD by the steep drop in the curve in these regions. We caution the reader that no conclusions should be made for these specific magnitudes. Rather, they stem from the approximations underlying the assessment methods.

The distribution in Figure 9 is a combination of events in each of four regions. We can examine the contribution of each region to the summary distribution by eliminating disruptions in other regions (assuming no disruption occurs) and showing the results for a region independently. Figure 10 shows each region independently on the same excess probability graph. Other Persian Gulf and West of Suez regions have the larger probabilities of disruption (for any given disruptions size) than Saudi or Russian and Caspian States.[2] The probability of any disruption is 80%, 72%, 48%, and 23% for Other Persian Gulf, West of Suez, Saudi, and Russian and Caspian States, respectively.

Figure 10. Comparison of Short-Duration Disruptions by Region



Long Duration and Very Long Duration disruptions show the same trends as Short Duration disruptions, but with decreasing probabilities.

[2] Minor exception at 8 MMBD

Figure 11. Comparison of Long-Duration Disruptions by Region

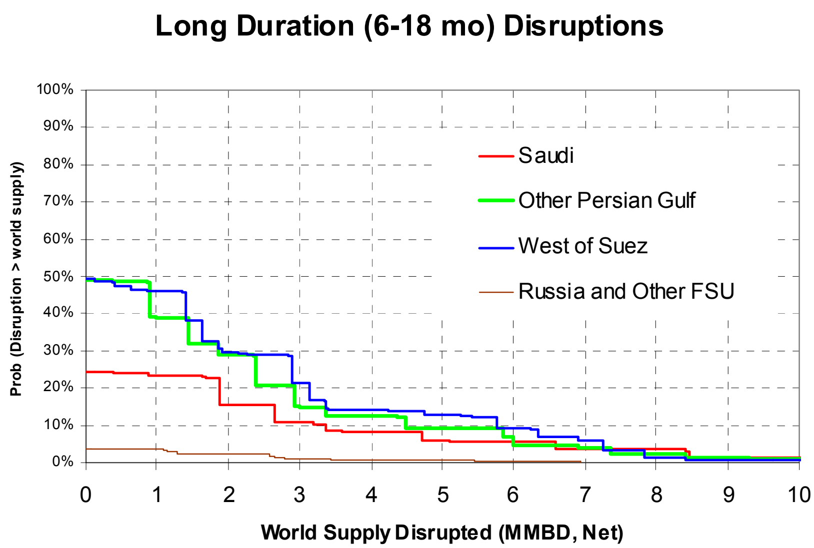


Figure 12. Comparison of Very Long-Duration Disruptions by Region

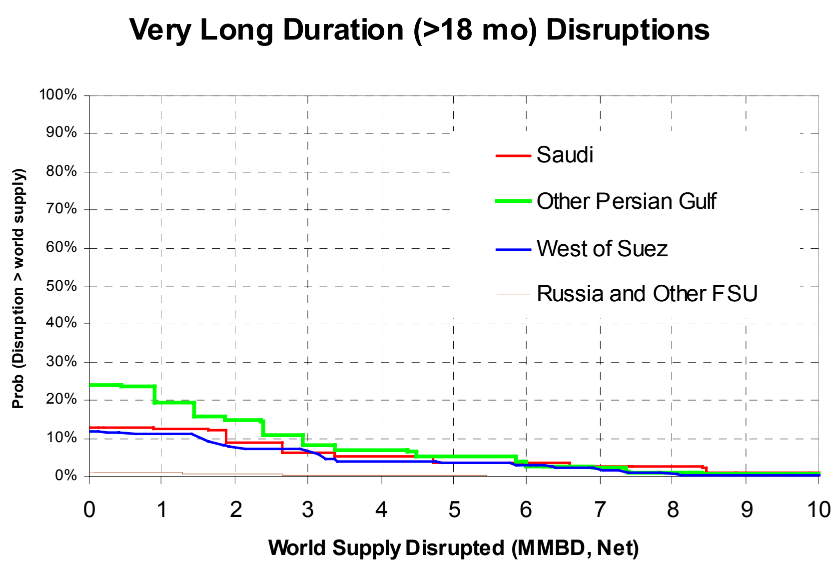
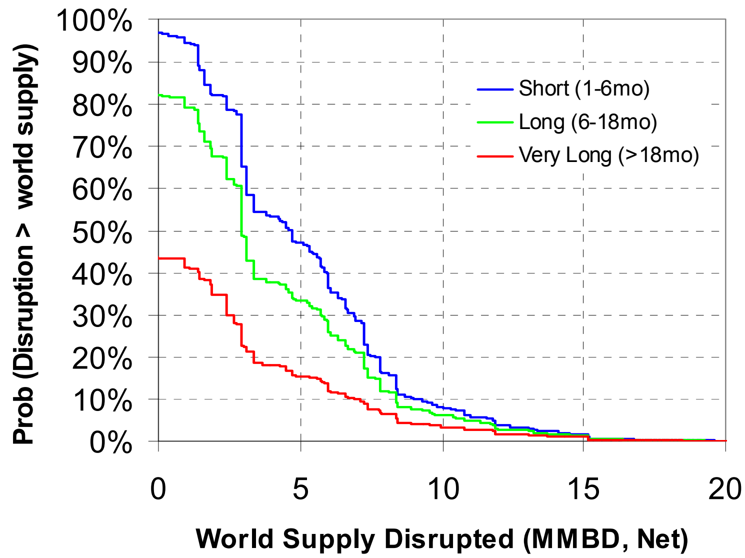


Figure 13. Probability of a Disruption for All Durations



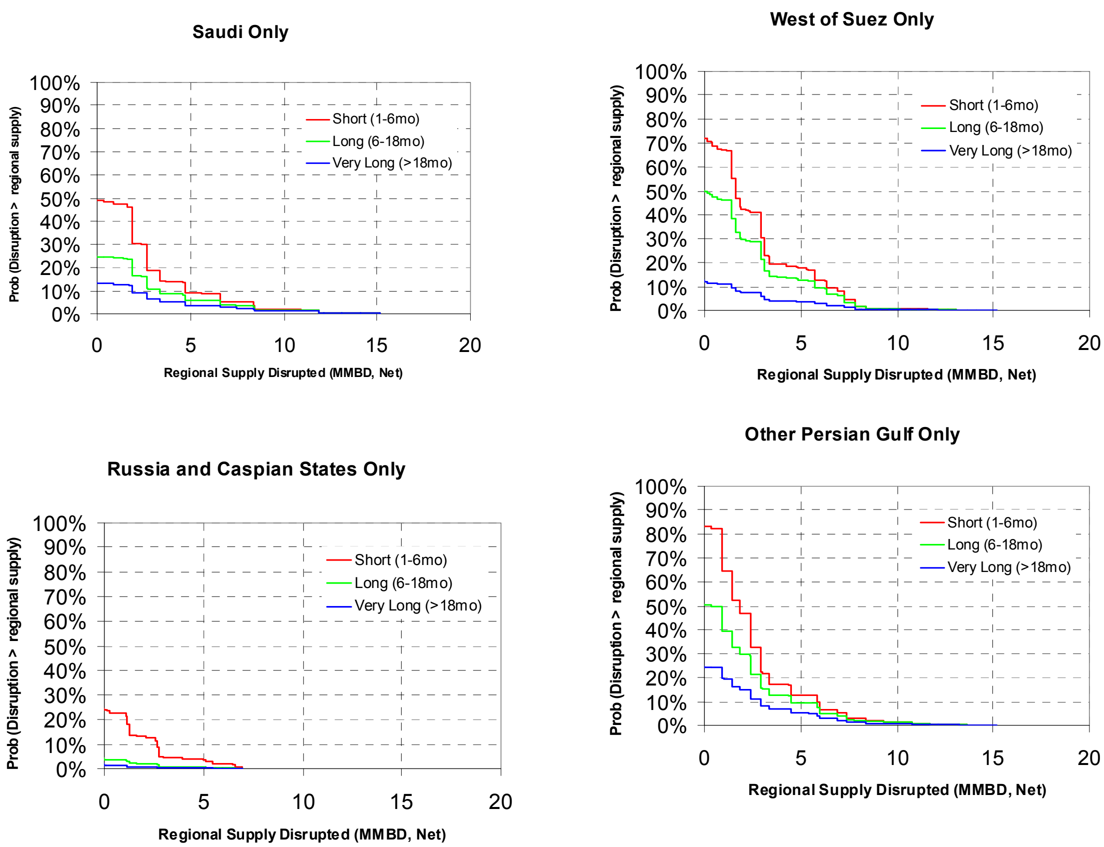
Combining all regions together, we can show all three durations on the same curve (Figure 13), providing a concise and powerful graphic that summarizes the magnitude, likelihood, and duration of oil disruption risks. Alternatively, the regional and combined probabilities of a disruption of at least 2 MMBD can be displayed in tabular format (Table 7), which highlights the Other Persian Gulf and West of Suez regions as significant contributors to overall risk for smaller (and more likely) disruptions.

Table 7. Probability of a Disruption > 2 MMBD by Region

Probability of a Disruption > 2 MMBD

Duration	**Saudi**	**Per Gulf**	**West Suez**	**Russia & Caspian**	**All regions**
Short (1-6 mo)	30%	47%	42%	10%	82%
Long (6-18 mo)	16%	29%	30%	2%	68%
Very Long (>18 mo)	9%	15%	8%	1%	35%

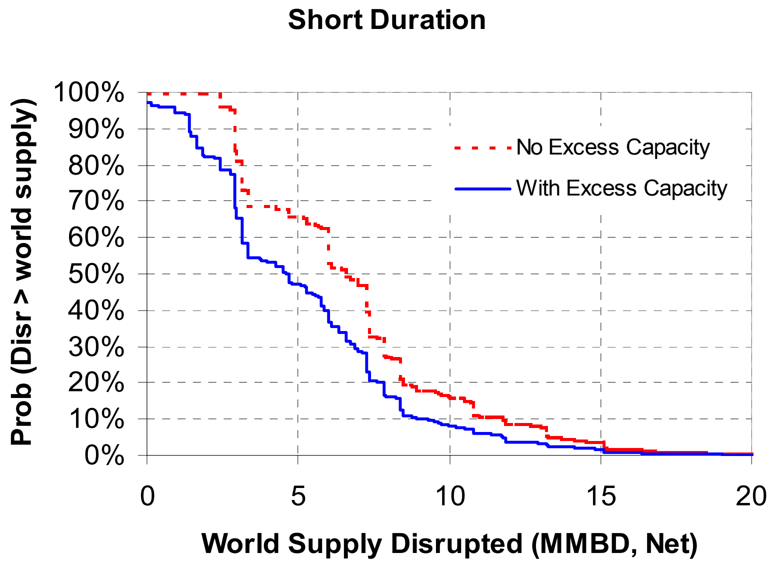
Figure 14. Probability of a Disruption by Region for Each Duration



The distributions in Figures 10-12 compare regional probability distributions by duration. We can also contrast the durations of a disruption for each region as shown in Figure 14. For Saudi Arabia and Russia/Caspian States, the shorter duration disruptions are much more likely than longer durations, whereas in Other Persian Gulf and West of Suez, the likelihoods of short, long, and very long disruptions are roughly similar.

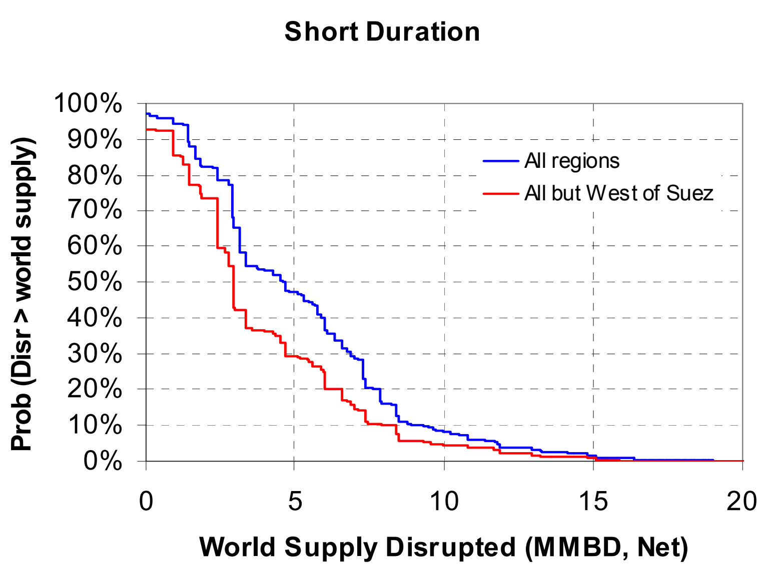
A sensitivity analysis testing the impact of offsets to the risk assessment is shown in Figure 15. With no excess capacity, a flat region between 0-3 MMBD represents a near certainty that a disruption of this magnitude will occur in the next 10 years. The effect of excess capacity tends to shift the distribution to the right by roughly 1 MMBD.

Figure 15. Sensitivity to Removing Excess Capacity



To test the effect that variations in probabilities of different regions have on the outcome of the risk assessment, a sensitivity analysis was performed on the West of Suez region by eliminating the possibility of disruptions from these countries. The West of Suez region is not only a key driver, but also a new region that was considered insignificant in terms of disruptions 10 years ago. The sensitivity analysis revealed that the probability of a disruption is 5% lower for sizes less than 3 MMBD, and 15% in the range of 3-7 MMBD. See Figure 16 for the West of Suez sensitivity comparison.

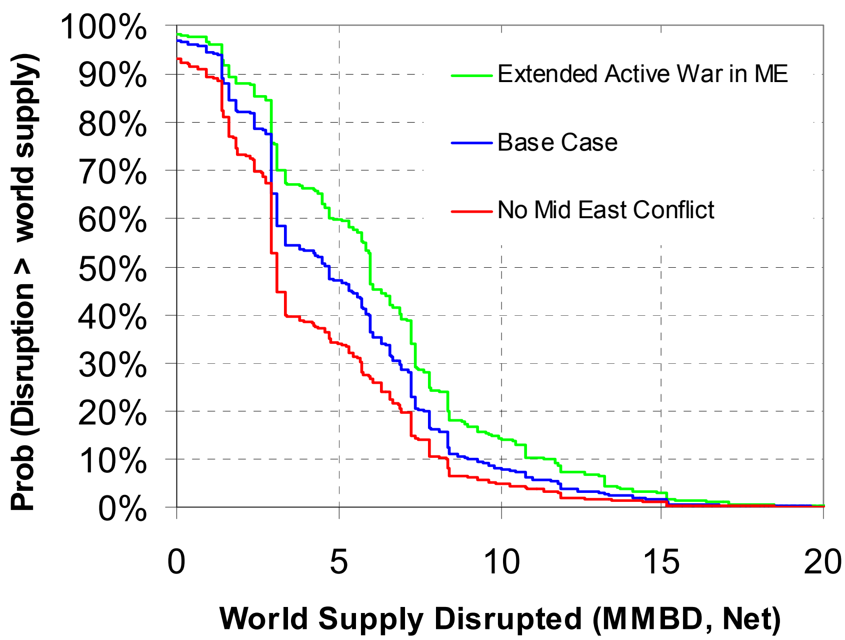
Figure 16. Sensitivity to Removing West of Suez Region



Other sensitivity analyses have the potential to reveal additional insights. During the assessment exercise, consensus on probability assignments were usually achieved for all event probabilities. However, there were two exceptions: higher probability of voluntary Saudi cutbacks, and higher probability of complete shortfall for Saudi and Middle East war. Both cases were tested and showed little variation in conclusions.

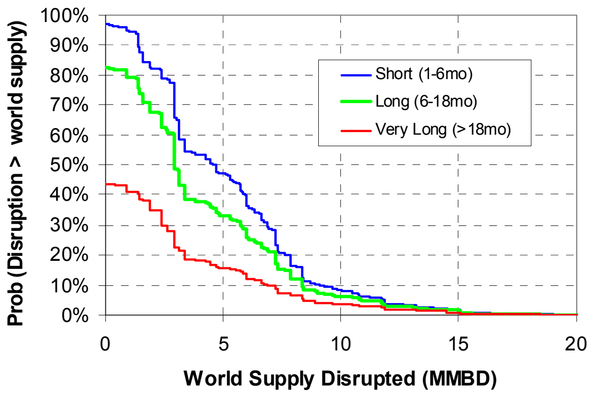
We examined the sensitivity to Middle East conflict, as it was believed that an underlying event affecting multiple regions together may have a significant impact on disruption risks. Figure 17 contrasts the base case assumptions with two cases representing the extreme conditions in the Middle East: stable conditions with no conflicts, and extended or active war in the region. At 5 MMBD or greater, the probability varied from 34% to 60%, confirming the notion that middle east events and their linkages to the regional shortfall risks are an important element of the oil risk assessment.

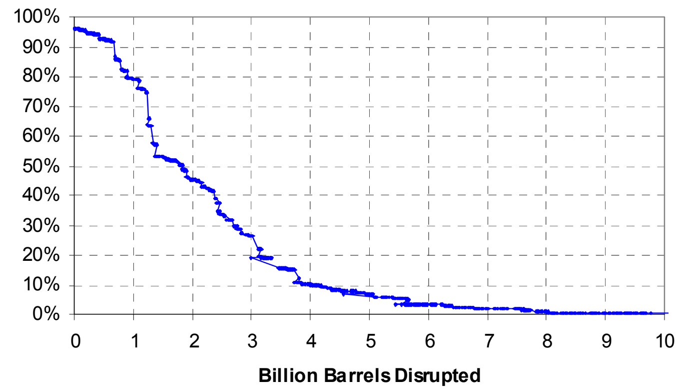
Figure 17. Sensitivity to War in the Middle East



The sponsors of this study are interested in the risk of oil disruptions expressed as a rate in million barrels per day disrupted. One logical question then arises: what is the range of total barrels lost to world supply, for various durations of outages? Although *Total Barrels Lost* was not part of the charter of the current study, we attempted to approximate this parameter. The probability distribution of Figure 13 summarizes all durations for each disruption magnitude. We assumed that short disruptions lasted 3 months, and long and very long disruptions had lengths of 12 and 24 months, respectively. For each disruption magnitude, the total barrels lost was computed, and then plotted against the associated probability. The results, shown in Figure 18, while not representing the focus of the risk assessment, is an interesting conclusion to inform SPR sizing issues.

Figure 18. Total Barrels Lost for a Given Disruption Size





SECTION 7. COMPARISON WITH PRIOR STUDIES

Besides the current study, three formal oil disruption risk assessments have been conducted in the past 15 years for the purposes of SPR sizing considerations: 1990 DOE Interagency study relying on statistical parameter estimation, 1996 EMF expert judgment incorporating decision analytic methods, and 1999 CIA-hosted workshop. Refer to the risk assessment alternatives comparison paper by Leiby/Bowman for further details on the approaches. In this section, we will compare the 1996 EMF study with the current 2005 EMF study, both of which rely on the same underlying methodology and processes. In fact, the DOE sponsors specifically requested the EMF to sponsor the current study, in part because of their belief in the validity and usefulness of the approach, and in part due to their interest in how the change in world events have influenced the conclusions of the 1996 EMF study.

We start by discussing changes in scope of the two studies, then compare and contrast the key inputs on event probabilities, shortfall probabilities, and excess capacity estimates. We conclude with a discussion of overall results for short and long duration disruptions.

In the 1996 study, experts identified two regions that had significant risk of disruptions (Saudi and Iran/Iraq/Kuwait); 2 additional regions were added to the 2005 study (West of Suez and Russia/Caspian states). Furthermore, the Iran/Iraq/Kuwait region was redefined as Other Persian Gulf, which added the three additional countries of Qatar, UAE, and Oman.

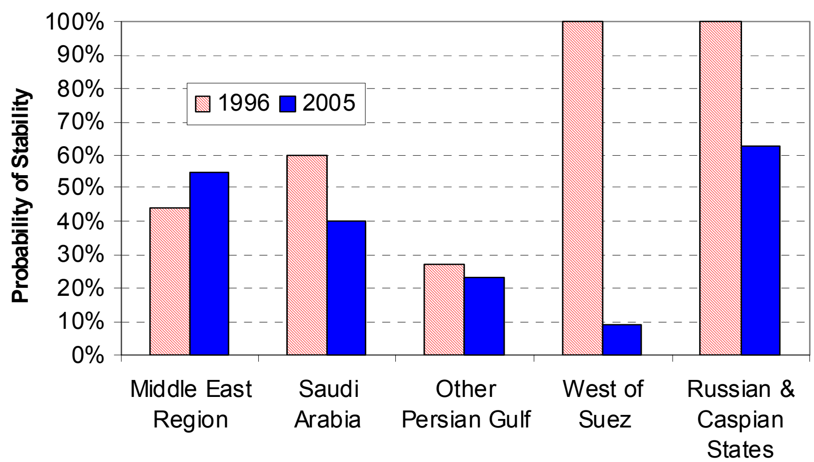
Each study contained one key underlying event (Middle East conflict) and an internal factor uncertainty associated with each region. The states of these events were defined somewhat differently in each study to reflect current world conditions and, ultimately, to yield a higher quality probability estimate because experts could more easily link their judgment to current perspectives. Nonetheless, it is interesting to compare the likelihood of particular states between the two studies as seen in Table 8.

The probability of stability in the Middle East has increased 10% from 44% to 54%, assuming no conflict and limited Arab-Israeli war are considered “stable” for Mid East Conflict. The probability of stable internal affairs for Saudi and Other Persian Gulf has dropped by 20% and 4%, respectively. Figure 19 shows a graphical comparison of stability probabilities, and for this viewpoint we assumed that the new regions (West of Suez and Russia/Caspian states) were considered stable with no disruptions so that in 1996 their chance of stability is 100%.

Table 8. Comparison of Event Probabilities with Prior Studies

1996		2005	
MID EAST CONFLICT		**MID EAST CONFLICT**	
Neutral	44%	No Conflict	5%
Big Iran/Iraq	30%	Limited Arab-Israeli War	49%
Big Player	22%	Spillover to Unrest	15%
Other Major	4%	Limited war Oil producer	21%
	100%	Extended active war	10%
			100%
Saudi Internal Factors		**Saudi Internal Factors**	
Status Quo	60%	Stable	40%
More sev int problems	30%	Stable with cutback	10%
Intentional reduction	10%	Insurgency - Intermittent disruptions	30%
	100%	Saudi hostile to west	15%
		Civil war - failed state	5%
			100%
Iran/Iraq/Kuwait Internal Factors		**Other Persian Gulf Internal Factors**	
Status Quo	27%	Stable except Iraq	23%
More sev int problems	71%	Stable except Iraq with cutback	12%
Intentional reduction	2%	Civil war or suc in 1	50%
	100%	Civil war or suc in 2	15%
			100%

Figure 19. Comparison of Probability of Stability



The size of shortfall had different states in the 1996 study (0% of supply, 33%, 75%, and 100% for the four defined states). In the current study we assumed 0%, 20%, 50%, and 90%. Table 9 shows that the probability of no shortfall in Saudi dropped from 76% to 50%, and from 47% to 11% in the Other Persian Gulf region. This explains a significant increase in the overall probability of a disruption. At the other extreme, the nearly complete disruption of supplies is roughly equivalent in Saudi (increasing from 2% in 1996 to 4% today) and in Other Persian Gulf (declining from 6% in 1996 to 2% today).

Table 9. Comparison of Shortfall Size for Short Duration Disruptions

	Size of Shortfall (% shortfall)	*Probability of Occurrence*	
		Saudi	**Other Persian Gulf**
2005	*0%*	50%	11%
	20%	35%	70%
	50%	11%	17%
	90%	4%	2%
		Saudi	**Iran/Iraq/Kuwait**
1996	*0%*	76%	47%
	33%	17%	32%
	75%	5%	15%
	100%	2%	6%

The excess capacity assumptions have declined in the past 9 years in terms of private stock, but increased in the Saudi region, both of which tend to balance each other for a net change of zero (see Table 10). In the current study we did not include private stock, while we assumed a 25% chance of 2 MMBD available from these sources in 1996. In the Saudi region, there was a 26% chance of between ½ to 2 MMBD available, while today there exists a 34% chance of 1.5 MMBD, with a small chance of up to 5 MMBD. The Other Persian Gulf region had no change in excess capacity assumptions since 1996. The net effect of excess capacity available, computed by taking the probability-weighted average of all amounts, is roughly 0.8 MMBD available for both. The full cumulative probability distributions for excess capacity in Figure 20 displays the comparison of effective excess capacity.

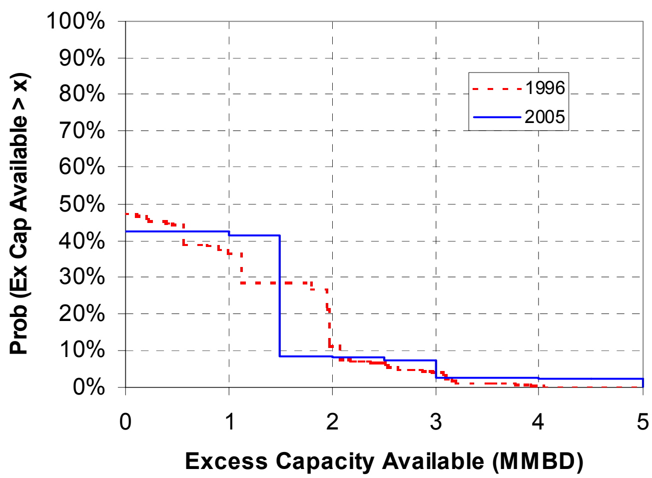
Table 10. Comparison of Effective Probability of Excess Capacity

Probability of Occurrence

Excess Capacity Available (MMBD) — 2005	Saudi	Other Pers Gulf
0.0	60%	98%
1.0		2%
1.5	34%	
2.0		0.3%
3.0	4%	0.3%
5.0	2%	

Excess Capacity Available (MMBD) — 1996	Saudi	Iran/Iraq/Kuwait	Private Stock
0.0	74%	96%	75%
0.2		3%	
0.4		1%	
0.6	8%		
1.0	13%		
2.0	5%		25%

Figure 20. Comparison of Effective Excess Capacity



The net effect of these changes (adding two regions, updated event probabilities, updated shortfall probabilities, modified excess capacity) is shown in Figures 21 and 22 for short and long duration disruptions. For short duration, disruptions greater than 10 MMBD in size are roughly equivalent in the two studies. However, in the 3-10MMBD range the probability of a disruption is 10-30% higher today, and below 3 MBMD it is 30-50% higher. Similar trends are found in the long duration (6-18mo) disruptions. No comparison is possible with disruptions lasting longer than 18 months as only 2 durations were considered in 1996. Energy security experts have concluded that current world events and energy markets have increased the likelihood of disruptions for all sizes up to 10 MMBD, while we can expect the same estimate as 1996 for disruption sizes of greater than 10 MMBD (7-8% or lower).

Figure 21. Comparison of Probability of Disruption for Short Durations

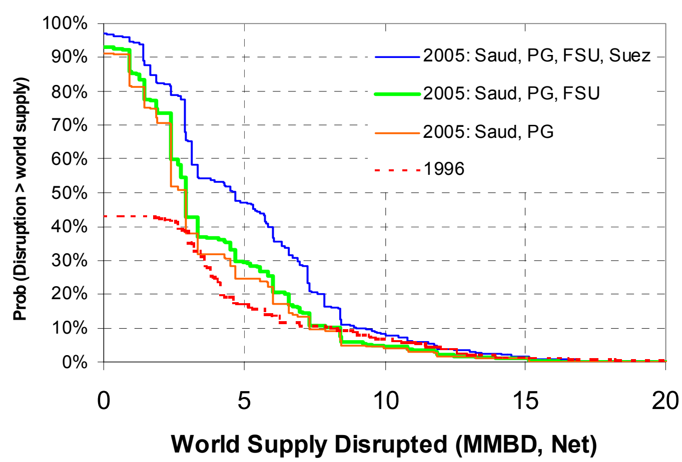
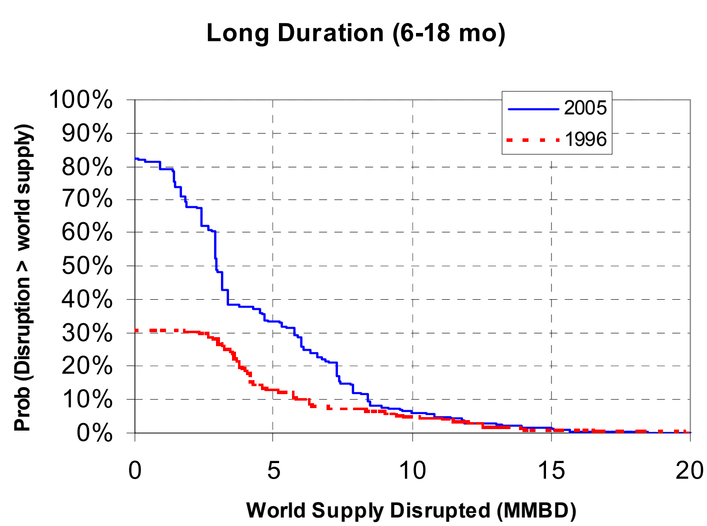


Figure 22. Comparison of Probability of Disruption for Long Durations



SECTION 8. SUGGESTIONS FOR FUTURE ASSESSMENTS

When assessing risks that are broad in their complexity, contentious in their implications, and highly subjective, it is critically important to engage a group of experts in a dialogue format and assess their collective judgment. The EMF oil disruption risk assessment took this approach, and thereby overcame some of the shortcomings of empirical analyses and modeling, and the tendency to focus on a large amount of detail for a limited set of issues. Many statistical approaches presume that the future behaves much like the past, a potentially limiting viewpoint.

The current framework for the assessment had some important benefits that we recommend for future assessments and updates. In only two meetings, we efficiently structured the scope of the assessment, defined variable definitions and scales, and developed inputs for 16 uncertain variables covering over 300 probability inputs. The concise tree-based algorithm[3] employed allowed for the computation and integration of over 23 million scenarios, with quick updating, intuitive accounting for complex dependencies, and clear outputs to policy-makers. By inviting experts from a wide array of geopolitical and industry perspectives, the current analyses proved to be an efficient synthesis of complex issues, capturing and documenting the logic and assumptions from multiple sources in a consistent framework. The structured interview and probability elicitation methods helped to minimize bias, promote communication among experts and study sponsors, and encourage an appropriate interaction among experts to calibrate results.

Can this study be repeated or revisited in the future? By building on the framework and methodology from the 1996 study, we demonstrated that a quality risk assessment could be repeated at minimal cost and time, even over a significant time gap and with new experts participating. There are a number of alternatives for future studies, and the tradeoffs among them should be carefully considered. Future updates could range from a similar study involving face-to-face interaction, to a more simple (but lower quality) approach which employs web-based surveys or teleconference meetings. 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. A summary of a select number of options is in Table 11.

Table 11. Alternatives for Future Oil Risk Assessments

Alternative	Pros/Cons
2-3 meetings with experts to revise problem structure and reassess	Highest quality; similar to current approach
1-2 meetings to reassess inputs, but keep same structure	Less effort, easy to compare, but customized scales may not apply
Web-based survey to reassess inputs	Less expensive, no meetings required, but limited to only a few experts' opinions, lose

[3] DPL decision tree and influence diagram software

	dialogue, refinement, calibration

The energy security workshops were 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 strategic alternatives that could mitigate the impacts of oil disruptions. The analysis and methods could also be employed on SPR sizing decisions.

SECTION 9. CONCLUSIONS

The feedback obtained from the panel of energy market and geopolitical 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. Careful attention was made to structure the risk assessment in an initial meeting prior to eliciting probability information. As a whole, the experts 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 risk assessment methodology presented is a useful approach to uncover probabilistic information and provide for a consistent and high-quality assessment.

A particular strength of the approach is that we assessed the beliefs about the likelihood of specific events, rather than arbitrary scenarios or an aggregate probability of a disruption. Furthermore, we were able to transparently define and capture the linkages among events, such as the instability of the Middle East region increasing the shortfall probabilities in surrounding regions. Another strength of our modeling framework is the integration of offsets in disruption magnitude, together with duration of disruption. The setting of expert workshops is an effective way to ensure the appropriateness of the framework. Experts were encouraged to iterate on their judgments after dialogue with other experts, which served to either confirm their original estimates or modify their viewpoints. Careful reflection and reconsideration was deemed a valuable component of the sessions. Collective judgment from a variety of experts is important to ensure that experts from diverse backgrounds can agree upon results of the probability assessments. Finally, the use of formal assessment techniques, along with a trained and neutral facilitator, helped to keep the panel focused and minimized unintended bias and undue influences from vocal participants.

Based on the experts' ability to work within the framework that was presented to them, and demonstrated by the repeatability of the 1996 EMF study on oil disruption risks, 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.

SECTION 10. APPENDICES

APPENDIX A: METHODOLOGY OVERVIEW

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.

This project is employing the decision analysis framework, which relies on a structured and thorough modeling methodology, together with the direct elicitation of probabilities from a panel of experts. Other approaches have been used, such as statistical analyses of historical frequencies and indirect methods (e.g., scenario analyses and risk indices).

"Risk" is defined as uncertainty regarding future adverse consequences. Consider an example of one adverse consequence: a 10 MMBD shortfall in production for six months in 2012. Risk assessment serves to determine what the adverse consequences could be and their relative likelihoods. 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 1) assessments are easier, 2) it facilitates assessments with groups of experts, 3) the quality of assessments tends to be high, and 4) 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 can be time intensive.

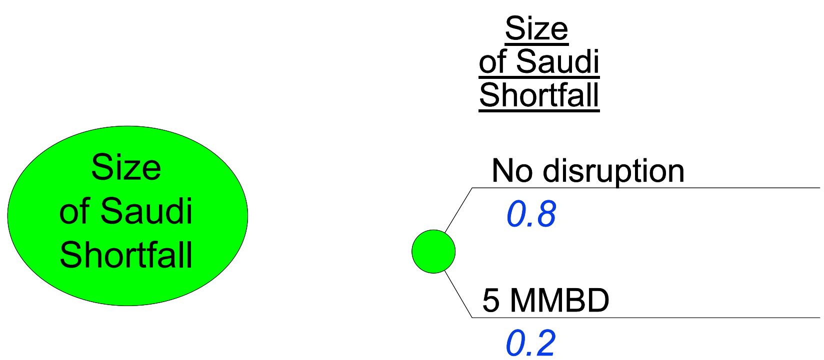
Probability assessments can be viewed as a quantitative representation of a person's knowledge. To ensure that probability assessments obtained from experts are authentic and reliable, formal procedures have been developed and were incorporated in this study. These include interview techniques to control 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 a simplified 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 A1 shows an event, which captures the uncertainty surrounding the size of a shortfall in oil production in Saudi Arabia.

Figure A.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 so that the probabilities assigned to each state sum to 100% and are consistent in their representation of the parameter under consideration. Figure A1 shows the states of the uncertain event "Size of Saudi Shortfall."

There are 2 branches because the uncertain event is 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 A1 we could not have the following two states since they overlap:

- Less than 1/4 capacity
- More than 10% of capacity.

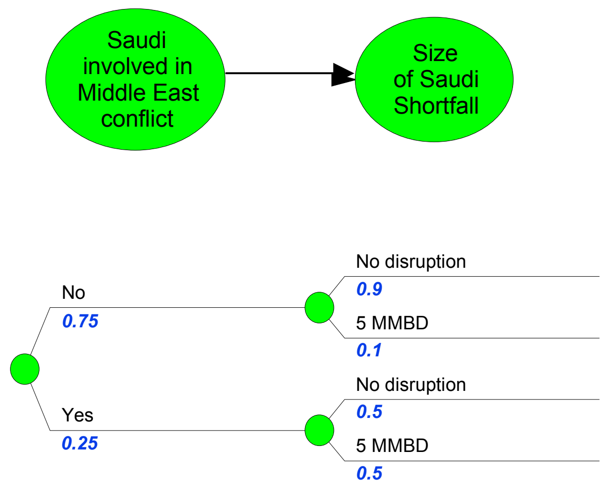
The collectively exhaustive condition means that all possibilities must be included. In Figure A1, we could not have the states

- 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 A2 shows an event (Saudi involved in a Middle East conflict) that influences the size of a Saudi shortfall.

Figure A.2. 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 simplified example to show how the calculations are performed.

Figure A.3. Sample Influence Diagram

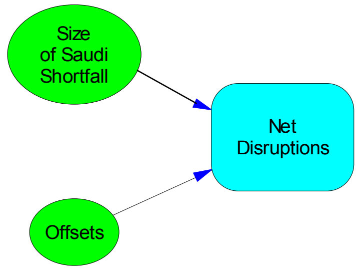


Figure A3 shows two independent events that influence the computation of the value "Net Disruption." The equation for net disruption is:

Net Disruption = Max (0, Size of Saudi Shortfall – Offsets)

Suppose that Size of Saudi Shortfall is defined with three states (None, Moderate, All) and the Offsets event with two states (None, 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 A4. The probabilities are shown beneath each branch on the probability tree.

For each scenario, we compute the joint probability by multiplying the probabilities 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 (top of Figure A5).

Figure A.4. Probability Tree for Performing Risk Assessment Computations

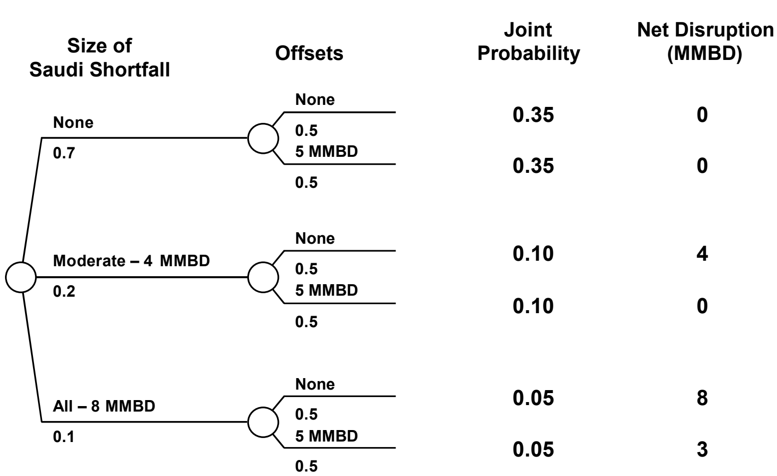
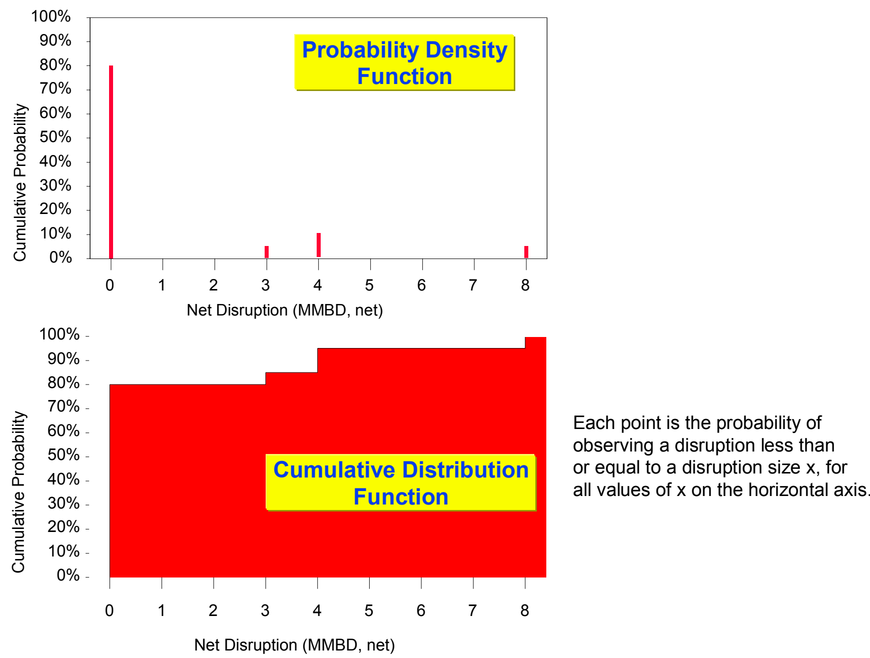


Figure A.5. Probability Density and Cumulative Distribution Function for "Net Disruption"



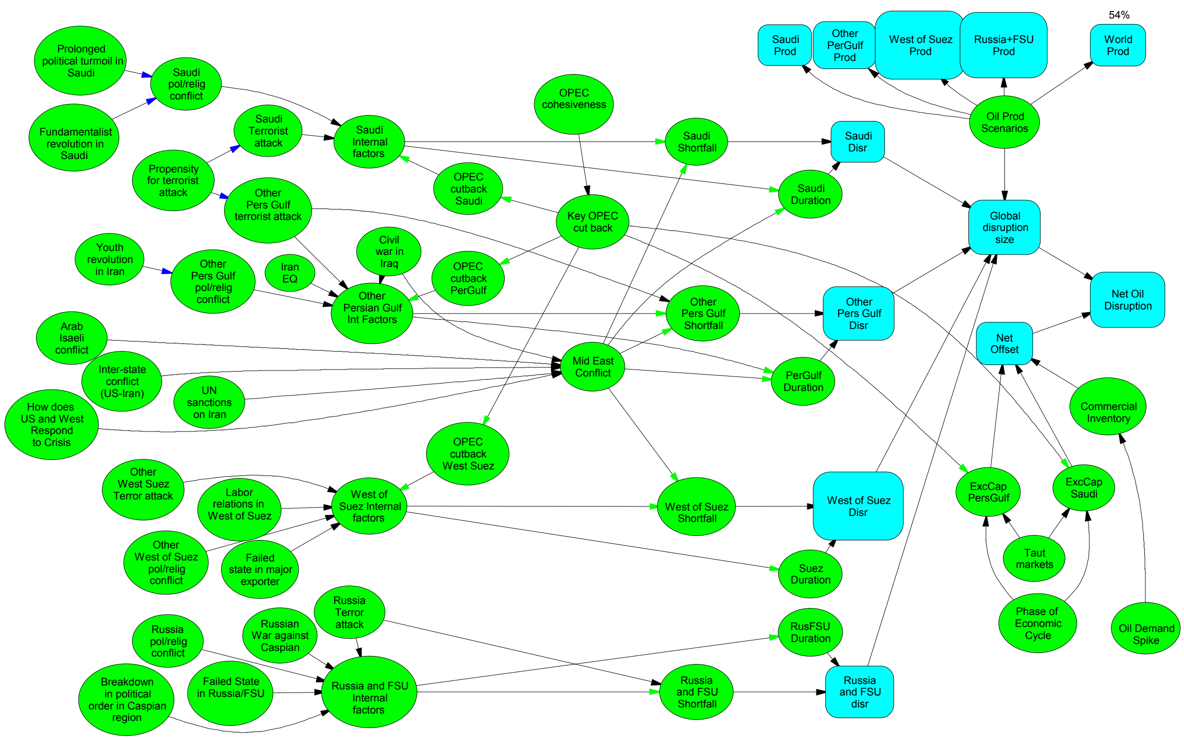
The probability density function shows the probability of a scenario as the height of the line for a given net disruption. With more scenarios, these functions may look like the common bell-shaped curves in a normal or lognormal shape. The cumulative probability distribution is a much more useful representation of the same result. Figure A5 also shows the 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 3.5 MMBD or less is 85%, obtained from adding the probabilities for 0 MMBD and 3 MMBD. The converse statement is stated as follows: "the chance that there will be a net disruption of size equal to or greater than 3 MMBD is 15% (1–0.85). In the sample 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 six scenarios, it is straightforward to translate probability assessments of uncertain events into resulting probability distributions. In the actual risk assessment with sixteen events and over twenty million scenarios, the cumulative probability distribution is a powerful way to compactly communicate the results of the assessments.

APPENDIX B: EVENT DEFINITIONS AND SCALES

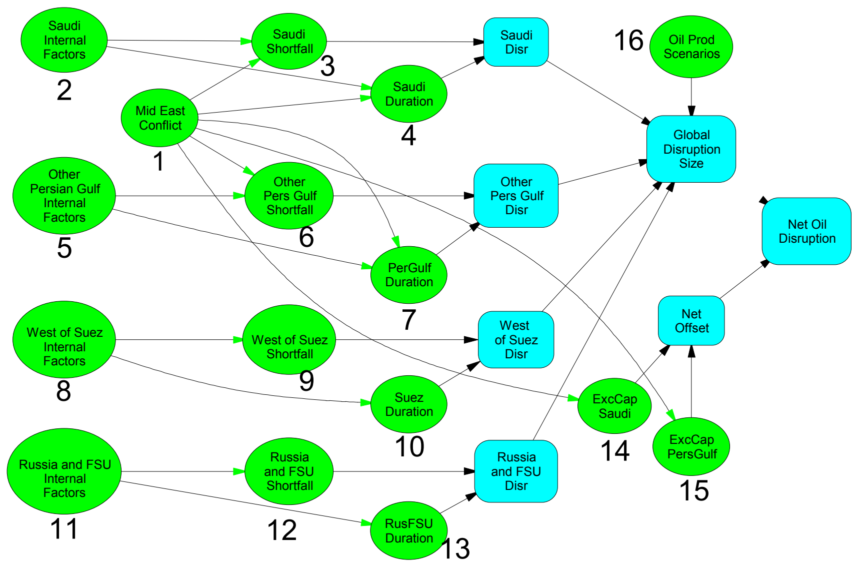
At the initial structuring meeting, the experts conducted a brainstorming session to identify as many sources of disruption as possible, along with causes and dependencies. A comprehensive influence diagram (Figure B1) was developed to represent the breadth of discussion and thought processes. In order to simplify the assessment to a manageable size, and to reflect the key parameters that matter most to the risk assessment, the comprehensive influence diagram was simplified to the one shown in Figure 1, repeated here again in Figure B2 for convenience.

Figure B.1. Comprehensive Influence Diagram of Key Factors Affecting Oil Disruption Risks



The influence diagram of Figure 1 (and B2) has numbered oval nodes that represent the entire set of probabilistic inputs in the risk assessment. This appendix will discuss the definitions and states for each numbered node, starting with underlying events, shortfalls, duration, excess capacity, and oil production.

Figure B.2. World Oil Disruption Influence Diagram



1. Middle East Conflict

Conflict among the states in the Middle East, e.g., invasion of Iraq by Iran, Iran launches air strike on Saudi, conflict between the Middle East and external states. The scale for this event consists of the following levels:

1) No conflict (any existing conflict ending quickly)

2) Limited war, including active insurgent operations, e.g., Arab/Iran - Israeli War

3) Spillover from one producer to chaos or unrest in other producers (not including Saudi)

4) Limited active war between oil producers and possibly U.S. (limited in time and scope); e.g., also could include UN sanctions instead of war

5) Extended active war in time and scope (e.g., among 1 or more producing countries with the involvement of the US and possibly Israel, unsettled conditions and internal strife and an Israeli/Arab armed conflict)

2. “Saudi” Internal Factors

1) Stable internal affairs with no voluntary Saudi cutback

2) Stable internal affairs with voluntary Saudi cutback to maintain price target (this event is a voluntary cut back in an otherwise tight market; excludes the case of OPEC quotas which are designed to handle excess capacity problems; “oil weapon” case)

3) Low level insurgency, intermittent oil disruptions

4) Saudi government hostile to the West, continuing turmoil/tension which causes most skilled workers to leave; Saudi government not able to attract new workers; insurgency makes them feel unsafe; government is hostile to them

5) Civil war or potential failed state

5. “Other Persian Gulf” Internal Factors

1) Stable internal affairs except Iraq with no voluntary Other Persian Gulf cutback

2) Stable internal affairs except Iraq with voluntary Other Persian Gulf cutback

3) Civil war or prolonged succession in 1 major producer, e.g., Iraq/Iran

4) Simultaneous civil war or prolonged succession turmoil in 2 or more major producers

8. “West of Suez” Internal Factors

1) Stable internal affairs with no voluntary West of Suez cutback

2) Stable internal affairs with voluntary West of Suez cutback

3) Civil war or labor disputes in 1 major producer

4) Extended civil war, terrorist attack or turmoil in 2 or more major producers

11. “Russia & Caspian States” Internal Factors

1) Stable internal affairs with no voluntary Russia & Caspian States cutback

2) Stable internal affairs with voluntary Russia & Caspian States cutback

3) Terrorist attacks on oil facilities

4) Prolonged ethnic insurgency in a major producing or transit region; or major border conflict among major producers

Four Shortfall Variables

A disruption is a sudden shortfall in oil production from a world supplier that results in at least 2 MMBD unavailable within 1 month of the beginning of the disruption. The disruption occurs at least one time during the 10-year period 2005-2014. Although the amount of shortfall in each region is a continuous variable, we approximate the variable as taking on one of four distinct states, expressed as a fraction of that region's supply. Taken together with total supply by region from the EIA forecast (Variable 16 below), we compute the net supply in MMBD. All Shortfall variables have the same states.

3. "Saudi," 6. "Other Persian Gulf," 9. "West of Suez," 12. "Russia & Caspian States"

1) No shortfall 0 - 10% of supply
2) Small shortfall: >10 - 30% of supply
3) Medium shortfall: >30 - 80% of supply
4) All: >80% of supply

Four Duration Variables

The duration of a regional shortfall, given that a disruption has occurred. This event addresses the question: "Given that a region's production facilities have been disrupted for the past 30 days, what are the chances it will last longer than 6 months?" or "Given that a region's production facilities have been disrupted for the past 6 months, what are the chances it will last longer than 18 months?" The scale for this event consists of three levels. All duration variables have the same states.

4. "Saudi," 7. "Other Persian Gulf," 10. "West of Suez," 13. "Russia & Caspian States"

1) Short: 1–6 months
2) Long: 6–18 months
3) Very Long: over 18 months

14. "Saudi" Excess Capacity

The amount of excess oil production capacity (MMBD) available in Saudi Arabia midway through the 10-year period 2005 - 2014. The capacity must be capable of being delivered to the world market within 1 month of a disruption. The scales for this event are:

1) 0 MMBD
2) 1.5 MMBD
3) 3 MMBD
4) 5 MMBD

15. "Other Persian Gulf" Excess Capacity

The amount of excess oil production capacity (MMBD) available from the Other Persian Gulf countries midway through the 10-year period 2005 - 2014. The capacity must be capable of being delivered to the world market within 1 month of a disruption. The scales for this event are:

1) 0 MMBD
2) 1 MMBD
3) 2 MMBD
4) 3 MMBD

16. Oil Production Scenarios

Three oil production scenarios are representative of the future uncertainty in oil price and supply. For the 10-year period 2005-2014, we used the Energy Information Administration's 2004 IEO forecast for the year 2010 as an approximation for the actual production at the time of a disruption. The scale for this event consists of the following three levels:

1) High Price (world capacity/price in 2010 = 90 MMBD/$33.28)
2) Reference (world capacity/price in 2010 = 95.1 MMBD/$24.18)
3) Low Price (world capacity/price in 2010 = 100.6 MMBD/$16.99)

APPENDIX C: PROBABILITY INPUT DATA

The risk assessment required probability inputs for 6 variable types:

- Global underlying events
- Regional internal factors
- Regional shortfall amounts
- Regional duration
- Future oil production
- Excess capacity

These inputs accounted for 16 uncertain variables covering over 300 probability inputs. The inputs are numbered according to the influence diagram of Figure 1. Although some inputs are shown in early parts of this report, they are repeated here for completeness.

Table C.1. Probabilities for Middle East Conflict

5%	1. No conflict (any existing conflict ending quickly)
50%	2. Limited war, including active insurgent operations, e.g., Arab/Iran - Israeli War
15%	3. Spillover from one producer to chaos or unrest in other producers (not including Saudi)
20%	4. Limited active war between oil producers and possibly U.S.(limited in time and scope); e.g., also could include UN sanctions instead of war
10%	5. Extended active war in time and scope (e.g., among 1 or more producing countries with the involvement of the US and possibly Israel, unsettled conditions and internal strife and an Israeli/Arab armed conflict)

Table C.2. Probabilities for Saudi Internal Factors

Alternate Opinion		
20%	40%	1. Stable internal affairs with *no* voluntary Saudi cutback
30%	10%	2. Stable internal affairs *with* voluntary Saudi cutback to maintain price target (this event is a voluntary cut back in an otherwise tight market; excludes the case of OPEC quotas which are designed to handle excess capacity problems; "oil weapon" case)
	30%	3. Low level insurgency, intermittent oil disruptions
	15%	4. Saudi gov't hostile to the West, continuing turmoil/tension which causes most skilled workers to leave; Saudi gov't not able to attract new workers; insurgency makes them feel unsafe; gov't is hostile to them
	5%	5. Civil war or potential failed state

Table C.3. Probabilities for Saudi Shortfall Amount

Middle East Conflict: No Conflict

Shortfall Amount \ Saudi Internal Factors	Stable - with no voluntary Saudi cutback	Stable - *with* voluntary Saudi cutback	Low-level insurgency - intermittent disr	Saudi govt hostile to West	Civil war or potential failed state
None (<10%)	95%	0%	30%	80%	0%
Small (10-30%)	5%	100%	60%	8%	20%
Medium (30-80%)	0%	0%	10%	5%	20%
All (>80%)	0%	0%	0%	7%	60%

Middle East Conflict: Limited War

Shortfall Amount \ Saudi Internal Factors	Stable - with no voluntary Saudi cutback	Stable - *with* voluntary Saudi cutback	Low-level insurgency - intermittent disr	Saudi govt hostile to West	Civil war or potential failed state
None (<10%)	85%	0%	20%	60%	0%
Small (10-30%)	10%	90%	60%	25%	20%
Medium (30-80%)	5%	10%	20%	10%	20%
All (>80%)	0%	0%	0%	5%	60%

Middle East Conflict: Spillover to unrest in others

Shortfall Amount \ Saudi Internal Factors	Stable - with no voluntary Saudi cutback	Stable - *with* voluntary Saudi cutback	Low-level insurgency - intermittent disr	Saudi govt hostile to West	Civil war or potential failed state
None (<10%)	95%	0%	30%	80%	0%
Small (10-30%)	5%	100%	60%	8%	20%
Medium (30-80%)	0%	0%	10%	5%	20%
All (>80%)	0%	0%	0%	7%	60%

Middle East Conflict: Limited or Extended active war

Shortfall Amount \ Saudi Internal Factors	Stable - with no voluntary Saudi cutback	Stable - *with* voluntary Saudi cutback	Low-level insurgency - intermittent disr	Saudi govt hostile to West	Civil war or potential failed state	*Alternate Opinion*: Civil war or potential failed state
None (<10%)	80%	0%	20%	60%	0%	0%
Small (10-30%)	10%	95%	60%	25%	15%	30%
Medium (30-80%)	10%	5%	20%	10%	15%	60%
All (>80%)	0%	0%	0%	5%	70%	10%

Table C.4. Probabilities for Saudi Shortfall Duration

Middle East Conflict	Stable - with no voluntary Saudi cutback	Stable - *with* voluntary Saudi cutback	Low-level insurgency - intermittent disruptions	Saudi govt hostile to West	Civil war or potential failed state
	Saudi Internal Factors				
1. No conflict (any existing conflict ending quickly)	*Group A*	*Group A*	*Group A*	*Group C*	*Group C*
2. Limited war, including active insurgent operations, e.g., Arab/Iran - Israeli War	*Group A*	*Group A*	*Group B*	*Group C*	*Group C*
3. Spillover from one producer to chaos or unrest in other producers (not including Saudi)	*Group A*	*Group A*	*Group B*	*Group C*	*Group C*
4. Limited active war between oil producers and possibly U.S.(limited in time and scope); e.g., also could include UN sanctions instead of war	*Group B*	*Group B*	*Group B*	*Group C*	*Group C*
5. Extended active war in time and scope (e.g., among 1 or more producing countries with the involvement of the US and possibly Israel, unsettled conditions and internal strife and an Israeli/Arab armed conflict)	*Group B*	*Group B*	*Group C*	*Group C*	*Group C*

Duration	*Group A*	*Group B*	*Group C*
Short (1-6mo)	80%	50%	20%
Long (6-18mo)	15%	30%	20%
Very Long (>18mo)	5%	20%	60%

Table C.5. Probabilities for Other Persian Gulf Internal Factors

If No Saudi Cutback	If Saudi cutback or turmoil	
32%	18%	1. Stable internal affairs except Iraq with *no* voluntary Other Persian Gulf cutback
4%	18%	2. Stable internal affairs except Iraq *with* voluntary Other Persian Gulf cutback
	50%	3. Civil war or prolonged succession in 1 major producer, e.g., Iraq/Iran
	14%	4. Simultaneous civil war or prolonged succession turmoil in 2 or more major producers

Table C.6. Probabilities for Other Persian Gulf Shortfall Amount

Middle East Conflict: No Conflict

Shortfall Amount \ Other Persian Gulf Internal Factors	Stable except Iraq with no voluntary Other PG cutback	Stable except Iraq *with* voluntary Other PG cutback	Civil war or succession in 1 major producer	Civil war or succession in 2 or more major producers
None (<10%)	90%	80%	15%	5%
Small (10-30%)	10%	20%	85%	85%
Medium (30-80%)	0%	0%	0%	10%
All (>80%)	0%	0%	0%	0%

Middle East Conflict: Limited war (incl. active insurg ops)

Shortfall Amount \ Other Persian Gulf Internal Factors	Stable except Iraq with no voluntary Other PG cutback	Stable except Iraq *with* voluntary Other PG cutback	Civil war or succession in 1 major producer	Civil war or succession in 2 or more major producers
None (<10%)	20%	20%	10%	0%
Small (10-30%)	75%	75%	80%	70%
Medium (30-80%)	5%	5%	10%	30%
All (>80%)	0%	0%	0%	0%

Middle East Conflict: Spillover to unrest in others

Shortfall Amount \ Other Persian Gulf Internal Factors	Stable except Iraq with no voluntary Other PG cutback	Stable except Iraq *with* voluntary Other PG cutback	Civil war or succession in 1 major producer	Civil war or succession in 2 or more major producers
None (<10%)	10%	10%	5%	0%
Small (10-30%)	85%	85%	75%	70%
Medium (30-80%)	5%	5%	20%	25%
All (>80%)	0%	0%	0%	5%

Middle East Conflict: Limited Active war, UN sanc. possible

Shortfall Amount \ Other Persian Gulf Internal Factors	Stable except Iraq with no voluntary Other PG cutback	Stable except Iraq *with* voluntary Other PG cutback	Civil war or succession in 1 major producer	Civil war or succession in 2 or more major producers
None (<10%)	20%	20%	0%	0%
Small (10-30%)	65%	65%	60%	50%
Medium (30-80%)	10%	10%	35%	40%
All (>80%)	5%	5%	5%	10%

Middle East Conflict: Extended active war

Shortfall Amount \ Other Persian Gulf Internal Factors	Stable except Iraq with no voluntary Other PG cutback	Stable except Iraq *with* voluntary Other PG cutback	Civil war or succession in 1 major producer	Civil war or succession in 2 or more major producers
None (<10%)	10%	10%	0%	0%
Small (10-30%)	60%	55%	55%	55%
Medium (30-80%)	25%	30%	35%	35%
All (>80%)	5%	5%	10%	10%

Table C.7. Probabilities for Other Persian Gulf Shortfall Duration

Other Persian Gulf Internal Factors (rows: **Middle East Conflict**)

Middle East Conflict	Stable except Iraq with no voluntary Other PG cutback	Stable except Iraq *with* voluntary Other PG cutback	Civil war or succession in 1 major producer	Civil war or succession in 2 or more major producers
1. No conflict (any existing conflict ending quickly)	*Group A*	*Group A*	*Group A*	*Group C*
2. Limited war, including active insurgent operations, e.g., Arab/Iran - Israeli War	*Group A*	*Group A*	*Group B*	*Group C*
3. Spillover from one producer to chaos or unrest in other producers (not including Saudi)	*Group A*	*Group A*	*Group B*	*Group C*
4. Limited active war between oil producers and possibly U.S.(limited in time and scope); e.g., also could include UN sanctions instead of war	*Group B*	*Group B*	*Group B*	*Group C*
5. Extended active war in time and scope (e.g., among 1 or more producing countries with the involvement of the US and possibly Israel, unsettled conditions and internal strife and an Israeli/Arab armed conflict)	*Group B*	*Group B*	*Group C*	*Group C*

Duration	*Group A*	*Group B*	*Group C*
Short (1-6mo)	80%	35%	10%
Long (6-18mo)	15%	40%	25%
Very Long (>18mo)	5%	25%	65%

Table C.8. Probabilities for West of Suez Internal Factors

Active war in mid east	No active war in mid east	
8%	10%	1. Stable internal affairs with *no* voluntary West of Suez cutback
2%	0%	2. Stable internal affairs *with* voluntary West of Suez cutback
	50%	3. Civil war or labor disputes in 1 major producer
	25%	4. Extended civil war, terrorist attack or turmoil in 2 or more major producers
	15%	5. Failed state in one of the major producers and labor unrest in another producer

Table C.9. Probabilities for West of Suez Shortfall Amount

Shortfall Amount \ West of Suez Internal Factors	Stable - with no voluntary West of Suez cutback	Stable - *with* voluntary West of Suez cutback	Civil war or labor disputes in 1 major producer	Extended civil war, terrorist attack or turmoil in 2 or more major producers	Failed state in one of the major producers and labor unrest in another producer
None (<10%)	90%	0%	20%	10%	5%
Small (10-30%)	10%	100%	65%	65%	50%
Medium (30-80%)	0%	0%	15%	25%	40%
All (>80%)	0%	0%	0%	0%	5%

Table C.10. Probabilities for West of Suez Shortfall Duration

Duration \ West of Suez Internal Factors	Stable - with no voluntary West of Suez cutback	Stable - *with* voluntary West of Suez cutback	Civil war or succession in 1 major producer	Extended civil war, terrorist attack or turmoil in 2 or more major producers	Failed state in one of the major producers and labor unrest in another producer
Short (1-6mo)	100%	80%	35%	35%	10%
Long (6-18mo)	0%	20%	55%	55%	45%
Very Long (>18mo)	0%	0%	10%	10%	45%

Table C.11. Probabilities for Russia & Caspian States Internal Factors

Active war in mid east	No active war in mid east	
70%	60%	1. Stable internal affairs with *no* voluntary Russia & Caspian States cutback
0%	10%	2. Stable internal affairs *with* voluntary Russia & Caspian States cutback
	20%	3. Terrorist attacks on oil facilities
	10%	4. Prolonged ethnic insurgency in a major producing or transit region; or major border conflict among major producers

Table C.12. Probabilities for Russia & Caspian States Shortfall Amount

Shortfall Amount \ Russia & Caspian States Internal Factors	Stable internal affairs with no voluntary Russia & Caspian cutback	Stable internal affairs with voluntary Russia & Caspian cutback	Limitation on output or transit due to terrorist attacks on oil facilities in Russia or on transit points or financial issues	Prolonged ethnic insurgency in a major producing or transit region; or major border conflict among major producers
None (<10%)	95%	0%	50%	45%
Small (10-30%)	5%	100%	30%	45%
Medium (30-80%)	0%	0%	20%	10%
All (>80%)	0%	0%	0%	0%

Table C.13. Probabilities for Russia & Caspian States Shortfall Duration

Duration \ Russia & Caspian States Internal Factors	Stable internal affairs with no voluntary Russia & Caspian cutback	Stable internal affairs with voluntary Russia & Caspian cutback	Limitation on output or transit due to terrorist attacks on oil facilities in Russia or on transit points or financial issues	Prolonged ethnic insurgency in a major producing or transit region; or major border conflict among major producers
Short (1-6mo)	95%	95%	85%	60%
Long (6-18mo)	5%	5%	10%	25%
Very Long (>18mo)	0%	0%	5%	15%

Table C.14. Probabilities for Saudi Excess Capacity

None	10%
1.5 MMBD	75%
3 MMBD	10%
5 MMBD	5%

Table C.15. Probabilities for Other Persian Gulf Excess Capacity

None	70%
1 MMBD	20%
2 MMBD	5%
3 MMBD	5%

Table C.16. Probabilities for Oil Production Scenarios

Oil Capacity (2010) from EIA's 2004-IEO

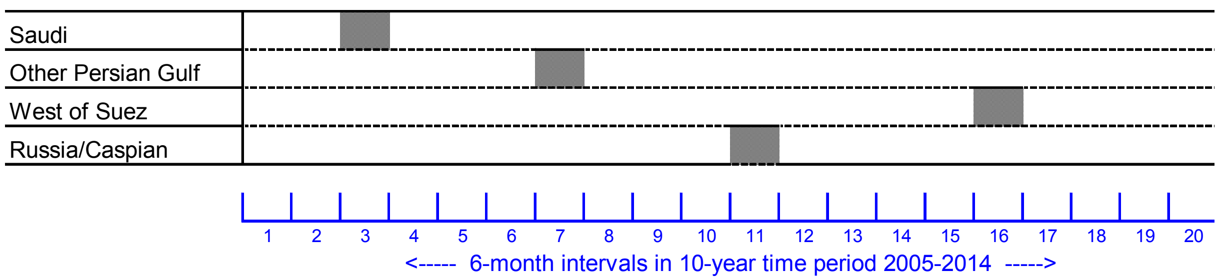
Country	High Price	Reference	Low Price
Iran	3.9%	4.2%	4.5%
Iraq	3.2%	3.9%	4.4%
Kuwait	2.6%	3.3%	3.6%
Saudi Arabia	10.4%	13.9%	16.7%
Total Persian Gulf	23.8%	29.3%	33.4%
Nigeria	2.4%	2.7%	3.0%
Venezuela	3.6%	3.9%	4.3%
Total Other OPEC	11.3%	12.4%	12.9%
Total OPEC	35.1%	41.7%	46.3%
Former Soviet Union	15.4%	13.9%	12.8%
United States	11.0%	10.0%	9.1%
Total Industrialized	28.4%	26.1%	23.9%
Total Non-OPEC	64.9%	58.3%	53.7%
Total World	100.0%	100.0%	100.0%
Levels			
Capacity (MMB/Day)	90	95.1	100.6
Price (2002$/B)	33.28	24.18	16.99
Probability	**50%**	**35%**	**15%**

APPENDIX D: DISRUPTION SIZE AND OVERLAP

When oil disruptions occur in two or more regions, they either overlap and occur simultaneously in the 10-yr horizon, or do not overlap so that the supply is brought back to original levels prior to the next disruption event. If the shortfalls occurred simultaneously, the disruption sizes are added together. However, if the shortfalls occurred at different times, then we assume the largest of the shortfalls is relevant, and ignore the smaller sizes.

Approximations of the probability of an overlap of regional shortfalls, given that two or more regions experience a disruption, were derived analytically from assumptions around shortfall length and that a shortfall is equally likely to occur at any time in the 10-yr window. Figure D1 shows a representative timeline for the unlikely case that all four regions experience a shortfall, but at different times. The shortfalls are all 6 months in duration, and fall in one of twenty segments in the 10-year horizon. Shortfalls could either overlap with each other, or occur in different segments. With overlap, the magnitudes of the disruptions are added. Without overlap, the largest magnitude is considered and the smaller magnitude(s) disruption is ignored.

Figure D.1. Timeline for Short Duration Disruptions



A highly stylized example would involve two regions with two periods. There is an equal chance that the disruption in a region will happen in either period. This means that for either period, there are four equally likely different states: both regions can be stable, one can be disrupted while the other is stable (two different states), or both can be disrupted at the same time. The chance of overlap, that they will both be disrupted at the same time, equals 25 percent.

This study involves a more complicated situation with four different regions and multiple time segments. If shortfalls last 6 months, they occur in 1 of 20 segments. If shortfalls last 12 months, they occur in 1 of 10 segments. If s = number of segments in the time horizon, then the probability of an overlap with four different regions can be determined analytically and expressed as

$$\text{Prob(overlap)} = 1 - \frac{(2s-3)*(2s-2)}{(2s-1)*(2s-1)}$$

Figure D.2. Probability of Overlap for Different Segment Sizes

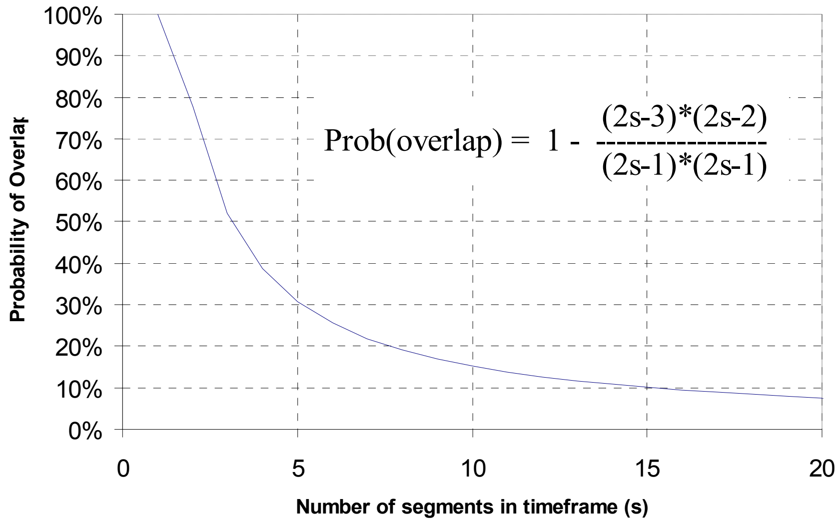


Figure D2 shows probability of overlap for various values of segment numbers s. Short disruptions last approximately 6 months and have s=20. Long disruptions last approximately 12 months and have s=10. Very long disruptions last 40 months and have s=3.

To minimize the number of permutations in the analysis, we first considered the likelihood that Saudi and Other Persian Gulf had an overlap. Then, we considered whether West of Suez overlapped with either of these two regions. Finally, we considered whether Russia/Caspian region overlapped with any of these three regions. Applying the overlap formula, the probabilities of overlap are shown in Figure D3.

Figure D.3. Probability of Overlap for Different Groups and Durations

	Probability that "n" regions overlap		
	n=2	**n=3**	**n=4**
Short	8%	15%	15%
Long	15%	28%	15%
Very Long	50%	77%	15%

Considering Short durations only, there is a 2/3 chance that no overlap will occur, and high probability because the length of disruption relative to the time horizon is small. The chance of no overlap diminishes with Long disruptions to 52%, and drops to only 10% for Very Long disruptions for which supply is not replenished for 3 years. Figures D4, D5, and D6 illustrate the probability of overlap occurring for none, two regions, three regions together, and all four regions.

Figure D.4. Probability of Overlap for Short Duration Disruptions

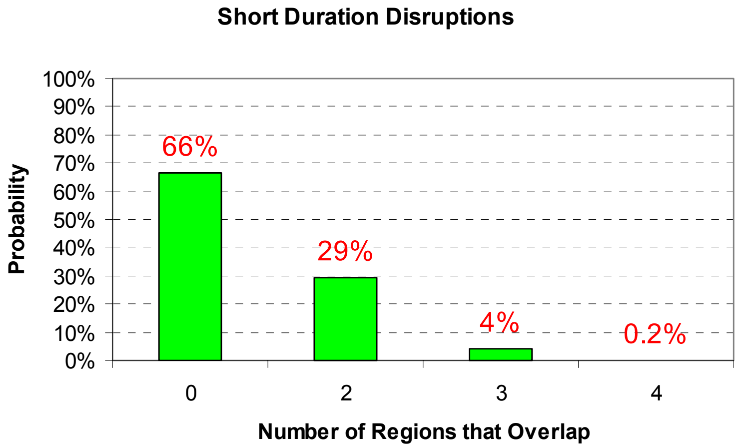


Figure D.5. Probability of Overlap for Long Duration Disruptions

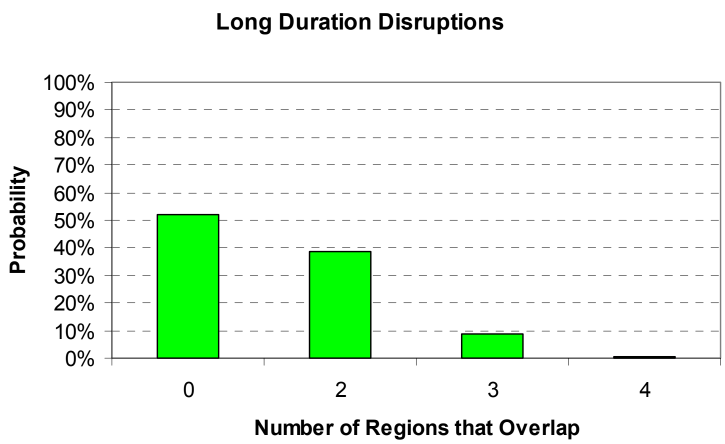
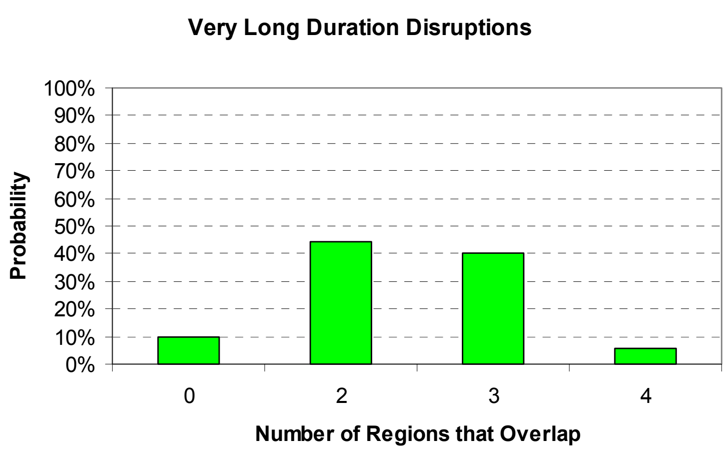


Figure D.6. Probability of Overlap for Very Long Duration Disruptions



APPENDIX E: HISTORICAL DISRUPTIONS

Table E.1. Historical Disruptions

#	Oil Supply Disruption Event Description	Cause of Disruption	Start Date Months	Disruption Length Months	Gross Shortfall MMBD
1	Iranian Fields Nationalized	Embargo/Economic Dispute	03/01/51	44.7	0.7
2	Suez War	Mideast War	11/01/56	5.0	2.0
3	Syrian Transit Fee Dispute	Embargo/Economic Dispute	12/01/66	4.0	0.7
4	Six Day War	Mideast War	06/01/67	3.1	2.0
5	Nigerian Civil War	Internal Struggle	07/01/67	16.3	0.5
6	Libyan Price Controversy	Embargo/Economic Dispute	05/01/70	9.2	1.3
7	Algerian-French Nat'l Struggle	Internal Struggle	04/01/71	5.1	0.6
8	Lebanese Political Conflict	Internal Struggle	03/01/73	3.1	0.5
9	October Arab-Israeli War	Mideast War & Embargo/Economi	10/01/73	6.1	1.6
10	Civil War in Lebanon	Internal Struggle	04/01/76	2.0	0.3
11	Damage at Saudi Oilfield	Accident	05/01/77	1.0	0.7
12	Iranian Revolution	Internal Struggle	11/01/78	6.0	3.7
13	Outbreak of Iran-Iraq War	Mideast War	10/01/80	4.1	3.0
14	UK Piper Alpha Offsh. Plat. Expl	Accident	07/01/88	17.3	0.3
15	UK Fulmer Float. Stor. Vess. Acc	Accident	12/01/88	4.0	0.2
16	Exxon Valdez Accident	Accident	03/24/89	0.5	1.0
17	UK Cormorant Offshore Platform	Accident	04/01/89	3.0	0.5
18	Iraq-Kuwait War	Mideast War & Embargo/Economi	08/01/90	12.0	4.6
19	Unilateral Embargo on Iran	Embargo/Economic Dispute	8/1/1995	1.0	0.2
20	Norwegian Oil Workers Strike	Internal Struggle	5/1/1996	1.0	1.0
21	Local Protests in Nigeria	Internal Struggle	3/1/1997	1.0	0.2
22	Local Protests in Nigeria	Internal Struggle	3/1/1998	3.0	0.3
23	OPEC (ex. Iraq) cuts production	Embargo/Economic Dispute	4/1/1999	12.0	3.3
24	Venezuelan Oil Strike	Internal Struggle	12/2/2002	2.5	2.0
25	Iraq War	Mideast War	3/19/2003	1.4	1.9

Source: Compiled from the U.S. EIA by Paul Leiby. See EIA website, "Global Oil Supply Disruptions Since 1951," http://www.eia.doe.gov/security/distable.html for one version of these data. Categorizations suggested by Paul Leiby.

APPENDIX F: REFERENCES

Clemen, R.T. 1996, *Making Hard Decisions: An Introduction to Decision Analysis*, second edition, Duxbury Press, Belmont, CA.

Huntington, H., J. Weyant, A. Kann and P. Beccue, "Quantifying Oil Disruption Risks Through Expert Judgment" Energy Modeling Forum Special Report 7, Stanford University, Stanford, California, April 1997.

Kahneman, D., Slovic P., and Tversky, A. eds. 1982, *Judgment under Uncertainty: Heuristics and Biases*, Cambridge University Press, Cambridge, UK.

Leiby, P. and Bowman, D., 2003, "Oil Market Disruption Risk Assessment: Alternatives and Suggested Approach," Oak Ridge National Laboratory internal report.

Merkhofer, M.W. 1987, "Quantifying Judgmental Uncertainty: Methodology, Experiences, and Insights," *IEEE Transactions of Systems, Man, and Cybernetics*, Vol. SMC-17, No. 5, pp. 741-752.

Spetzler, C.S. and Staël von Holstein, C.-A.S. 1975, "Probability Encoding in Decision Analysis," *Management Science*, Vol. 22, No. 3, pp. 340-352.

Syncopation Software (2003). DPL 6.0 Professional Getting Started Guide. Syncopation Software, Inc., Concord, MA.