An Updated Assessment of Oil Market Disruption Risks

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SECTION 1. EXECUTIVE SUMMARY

The probability of the size and duration of another oil disruption is critical to estimating the value of the Strategic Petroleum Reserve (SPR) and its desired size. Recent changes in world events, tensions in other parts of the world, and energy markets (oil price decreases), along with the dramatic surge in North American tight oil supplies from shale formations have renewed interest by the Department of Energy (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 one or more foreign oil disruptions 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 outside the U.S. 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 and time frame available for the project.

The risk assessment was conducted through a series of two 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 world oil market was divided into 5 primary regions of production: Saudi Arabia, Other Persian Gulf, Africa, Latin America, and Russian / Caspian States. Taken together these regions account for 57% of the world production of 98 MMBD (as projected by the U.S. Energy Information Administration for 2020). The panel of experts also considered choke point disruptions at vulnerable shipping lanes. Not included in the assessment were geopolitical disruptions from the US market and smaller global producers. Excess capacity was considered as a source to mitigate oil disruptions and therefore a primary output of the assessment is "Net Disruptions" or the total disruption less the excess capacity available.

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 (e.g., OPEC spare capacity), with the notable exception that the SPR is not included as a source of offsets. At least once during the 10-year time frame 2016-2025:

- The probability of a net (of offsets) disruption of 2 MMBD (million barrels per day) or more lasting at least 1 month is approximately 80%.
- The probability of a net (of offsets) disruption of 2 MMBD or more lasting at least 6 months is approximately 63%.
- The probability of a net (of offsets) disruption of 2 MMBD or more lasting at least 18 months is approximately 37%.

- The chance of a 3 MMBD net disruption or more lasting at least 1 month is 67%; the chance of 5 MMBD or more is 42%.
- The net effect of a disruption at Middle East choke points is a 4% probability for an 8 MMBD disruption and a 15% probability of a 4 MMBD, both of which are likely to be mitigated within a short (6 month) time frame.
- There is a greater probability for any disruption lasting >1 month in the Other Persian Gulf region (60%) comprised of Iran, Iraq, Kuwait, Qatar, UAE and Oman, than in Saudi Arabia (48%) or Africa (48%) comprised of Algeria, Angola, Libya, and Nigeria, while the Russian and Caspian states have a 38% probability and Latin America the lowest chance (23%).
- The chance of 5 MMBD disruption size (or greater) is 64% for interstate conflict between two or more standing governments in the Middle East, 36% for the current state of unrest and strife with insurgent groups, and 26% assuming relatively stable middle east politics as we saw prior to the Arab Spring.

The probabilities of a disruption for the dimensions above, including Size, Duration, Region, and State of Middle East Conflict, are reflected in the graphs and tables in the body of this report, and are also summarized in Table 1.

Table 1. Probability of an Oil Disruption by Size, Duration, Region, and State of ME Conflict

	Probability of a Disruption:			
	> 0 MMBD	> 2 MMBD	> 3 MMBD	> 5 MMBD
DURATION				
Short	96%	80%	67%	42%
Long	82%	63%		
Very Long	53%	37%		
REGION				
Africa	62%			
Other Persian Gulf	61%			
Saudi Arabia	48%			
Russian / Caspian States	40%			
Latin America	28%			

MIDDLE EAST CONFLICT STATE	> 5 MMBD
Stable politics as we saw prior to Arab Spring	26%
Current state of unrest and strife	36%
Interstate conflict with 2 or more standing governments	64%

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%-10%.

A similar risk assessment was conducted by the EMF in 2005. The current assessment covers five regions of the world instead of four regions, explicitly considers disruptions at choke points, has updated probabilities to reflect current world conditions, and has modified excess capacity and oil supply forecasts. The net effect of these changes shows only a very small decrease in likelihood of disruptions between 4 and 7 MMBD, but similar estimates for all other disruption sizes.

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.

The Stanford Energy Modeling Forum has sponsored an assessment of oil disruption risks for the Department of Energy twice in the past 20 years (1996, 2005). The geopolitical climate regarding oil production has seen significant change in the past 10 years since the previous study. This fact, together with pressure to understand the value of the Strategic Petroleum Reserve has prompted considerable interest to update the risk assessment to reflect current conditions. Responsible policymaking requires a quantitative and thoughtful evaluation of these important risks and overall energy security.

In this study, 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.

This risk assessment is part of a larger project initiated by the Strategic Petroleum Reserve Office to evaluate the benefits and costs of maintaining, expanding and using public oil stockpiles. It addresses only one of many critical issues in the SPRO analysis. By itself, it does not determine what the appropriate strategy should be. Nor does it cover all the important considerations that influence those decisions.

In particular, given the limited time and resources for the project, this assessment limits its focus in the following ways:

- The working group focused on geopolitical events leading to disruptions in global oil supply. Governments hold public oil stockpiles primarily to offset sudden lost production in the world oil market, thereby limiting price escalation during such events.
- Participants discussed such developments as hurricanes, pandemics and cyber-attacks, but many of the most serious possibilities would have major implications for wellbeing that extend well beyond oil supplies. Only if these events were focused on oil production, pipelines and shipping would they have more serious implications for maintaining and using public oil stockpiles.
- The study did not evaluate all major supply regions, but only those areas where geopolitical and military unrest were most pronounced. The five regions selected and their associated countries included more than 60 percent of total world oil production. The study did not address weather-related disruptions but did include possible cyber-attacks on oil production, transportation and distribution in these selected regions.
- Due to the limitations on the number of experts who could be elicited in this analysis, the risks may be understated by ignoring weather-related disruptions and cyber-attacks outside of these regions. If further investigation finds that these factors should be included in future evaluations, a risk-assessment approach similar to the one used in this study could be applied to these other events.
- The project focused on gross oil supply disruptions and any explicit supply offsets from excess oil production capacity from major producing countries.
- The project excluded inventory responses (drawdowns and increments), including those of public or private oil stockpiles within or outside of the United States.
- Public stockpile decisions by the United States were excluded because the evaluation focused on the oil market conditions in the absence of any drawdown of the U.S. strategic petroleum reserve. These conditions are most relevant to addressing the issue of whether or not public stockpiles should be used and by how much.
- The purpose was to assess geopolitical supply risks, and not the responses to, or consequences of, those events (except for the possible use of oil-producer excess capacity). Offsets also excluded any supply or demand response to price changes caused by the oil supply disruptions. These excluded supply adjustments include operating existing fields of conventional oil more intensively or extracting more volumes from oil-shale formations. It also did not address any demand-side adjustments that policymakers might use during a disruption such as forcing carpooling or gasoline rationing. Demand-reduction strategies provide gross benefit by reducing the shock, but they also impose costs by restricting driving patterns and causing citizens to make longer trips. The SPRO

already incorporates many of these adjustments in the models used for evaluating the benefits and costs of public oil stockpiles.

Although the main benefits of maintaining and using a public oil stockpile are linked directly to how it influences oil prices, the risk evaluation focuses on physical volumes of oil removed rather than price movements. The models operated by the SPRO use the physical volumes of oil removed as an assumption in order to derive oil price changes, after incorporating all of the market and policy adjustments discussed above.

Before discussing the detailed results of the risk assessment, we begin by describing the approach and review the key inputs developed by the experts. We conclude with comparisons from past studies, and a discussion of issues to consider for future assessments.

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) and in 2005 (EMF SR8, Beccue, Huntington 2005). 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 composed of 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 two workshops. The workshops took place in the Washington, D.C. area in September and October, 2015. 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 2.

Table 2. Participants in the 2015 Oil Risk Assessment

Tristan	Abbey	Senate Energy and Natural Resources Committee
Asmeret	Asghedom	DOE - Energy Information Administration
Phillip	Beccue	White Deer Partners
Cheryl	Brown	DOE - Office of Fossil Energy
Patrick	Clawson	The Washington Institute for Near East Policy
Matt	Cline	DOE - Office of International Affairs
Robert	Corbin	DOE - Office of Fossil Energy
Chris	Elsner	I H S Energy
Mark	Finley	British Petroleum
Oliver	Fritz	DOD - OSD Operational Energy
Melissa	Holtmeyer	DOD - OSD Operational Energy
Hill	Huntington	Stanford
James	Jewell	DOE - Office of Intelligence
Frederick	Joutz	George Washington University
Jim	Krane	Rice University
Sarah	Ladislaw	CSIS
Paul	Leiby	Oak Ridge National Laboratory
Geoff	Lyon	DOE - Office of Fossil Energy
Mariana	Manus	DOE - Office of Intelligence
Robert	Murphy	Chevron
John	Powell	DOE - Energy Information Administration
James	Preciado	DOE - Energy Information Administration
Deanna	Przybyla	White Deer Partners
Lou	Pugliaresi	Energy Policy Research Foundation Incorporated
John	Shages	Strategic Petroleum Consulting
Laura	Singer	DOE - Energy Information Administration

Pete	Steen	DOD - The Joint Staff J-5
Frank	Verrastro	CSIS
Lejla	Villar	Energy Information Administration
Kenneth	Vincent	DOE - Office of Fossil Energy
Rick	Westerdale	Department of State
Andrew	Zilm	Department of the Treasury

The workshops focused on incorporating expert judgment in the explicit quantification of the magnitude and likelihood of oil disruptions. In the first day of the workshop in September 2015, participants identified the key events that could lead to an oil disruption, organized the events, and created scales to assist in quantifying risks. The second workshop day in October 2015 consisted of assigning probabilities to the events that were discussed at the first workshop. Most of the participants in the list in Table 2 participated in both workshop days.

SECTION 4. SCOPE

SHORTFALL DEFINITION

Defining a shortfall is a particularly difficult challenge given the complexity of geopolitical events and the 10-year horizon for this study. To help make this effort manageable, we asked the experts to focus on events that have the potential to cause a 2 MMBD shortfall or more. An event may lead to a full loss of production from a particular region, or a partial loss. We considered events to be out of scope if there was no chance for at least a 2 MMBD loss. Therefore, we defined a disruption as:

> "A sudden shortfall in oil production from a world supplier that could potentially cause 2 MMBD to become 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-year period 2016-2025."

This definition provides guidance as the experts considered a range of potential events leading to 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, (3) Africa, (4) Latin America, and (5) Russia and Caspian states. Note that the Africa region includes both North Africa and Sub-Saharan Africa. We focused on these five oil supply regions and treated each set of countries within a region as a group. The primary oil producing countries in each region include:

Other Persian Gulf	Africa	Latin America	Russia and Caspian
Iran	Algeria	Brazil	Azerbaijan
Iraq	Angola	Mexico	Kazakhstan
Kuwait	Libya	Venezuela	Russia
Oman	Nigeria		Turkmenistan
Qatar			Uzbekistan
UAE			

The production capacity from this study's reference case for 2020 for each region is:

Saudi Arabia[1]	11.6 MMBD
Other Persian Gulf	15.5 MMBD
West of Suez	8.5 MMBD
Latin America	6.1 MMBD
Russia & Caspian	13.9 MMBD
TOTAL	55.6 MMBD

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

The risk assessment framework was developed in an initial one-day structuring meeting with energy security experts on September 23, 2015. The purpose of this meeting was to identify events that could lead to an oil disruption and organize these events into detailed influence diagrams that identify the primary factors contributing toward oil disruption risks, and the relationships between these factors. The influence diagrams were used as guidelines in developing constructed scales to help characterize the range of severity for each event. The output from this structuring meeting was a consensus view on the detailed influence diagrams and associated scales which served as a roadmap for the necessary probability assessments in the second set of meetings on October 28-29, 2015.

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 September 2015 workshop is shown in Figure 1.

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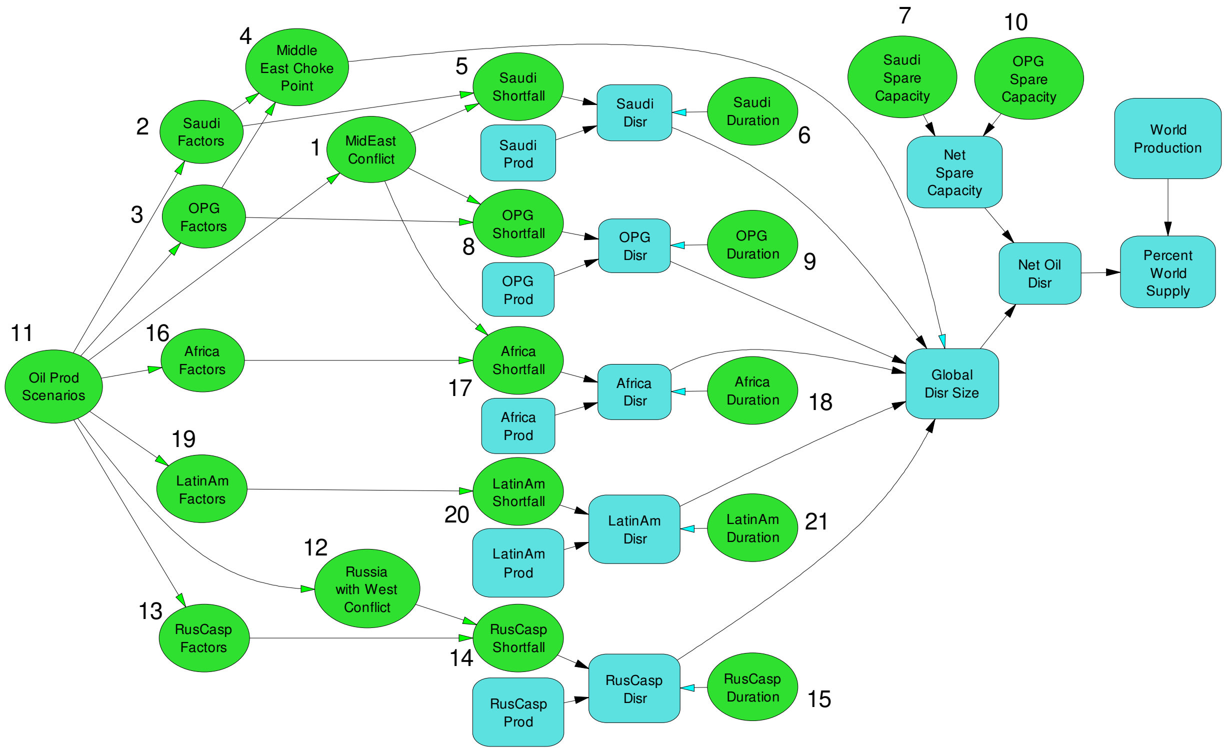
[1] The Saudi Arabia oil production is extrapolated from an estimate of production from the OPEC Middle East region based on the 2014 International Energy Outlook (IEO) reference case produced by the US Energy Information Administration. The project team allocated the remaining OPEC Middle Eastern volumes to Other Persian Gulf. Production for the other regions are based upon the 2014 IEO estimates.

Figure 1. World Oil Disruption Influence Diagram



The rounded blue rectangles represent calculated quantities or single point input values, and the green 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 21 numbered ovals represent the parameters requiring probability assessments. The influence diagram has internal factors for each of the five regions, and two underlying events which could influence more than one event. The internal events and underlying events impact the shortfall events which characterize the size and likelihood of a disruption. Shortfalls may be offset by excess capacity from Saudi Arabia and/or Other Persian Gulf. Net oil disruptions are calculated by summing global disruption size and subtracting net offsets (if offsets are available). Net oil disruptions are expressed in million barrels per day (MMBD), or as a percentage of world supply.

Each of the uncertain variables (ovals on the influence diagram) requires probability assessments from experts. Before we assessed the probability estimates, the experts established a clear and precise 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.

DURATION OF DISRUPTION

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 18-30 months. By this 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. Table 3 summarizes the three durations considered in the risk analysis and the months that were assumed in the calculations.

Table 3. Duration of Disruption

Duration	Definition	Months Used in Analysis
Short	1-6 months	6
Long	6-18 months	12
Very Long	> 18 months	24

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 regions. 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. We did not ask the experts when a particular event could occur, but in all the assessments the experts were instructed to consider that the event could occur any time within the next 10 years and we assigned equal likelihoods for any period. On a period-by-period basis, the analyses assumed that 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.

SECTION 5. EXPERT ASSESSMENTS

Developing the simplified influence diagram in Figure 1 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 assessment was preceded by a discussion of probability assessment techniques, with special attention to the types of expert biases and mechanisms to minimize bias.

The risk assessment required scale definitions and probability assessments on seven variable types: global underlying events, regional factors, regional shortfall, regional duration, choke points, future oil production, and excess capacity. Table 4 shows the entire set of variables assessed and are numbered according to the order in which they were assessed. These inputs will be discussed in the next sections organized by variable type.

Table 4. Assessment Variables

Asssessment Order	Assessment Variable	Variable Type
1	Middle East Conflict	Underlying Event
2	Saudi Internal Factors	Internal Event
3	Other Persian Gulf Internal Factors	Internal Event
4	Middle East Choke Points	Choke Points
5	Saudi Shortfall	Regional Shortfall
6	Saudi Duration	Regional Duration
7	Saudi Offsets	Excess Capacity
8	Other Persian Gulf Shortfall	Regional Shortfall
9	Other Persian Gulf Duration	Regional Duration
10	OPG Offsets	Excess Capacity
11	Oil Price Scenarios	Future Oil Production
12	Russia/West Conflict	Underlying Event
13	Russia/Caspian Internal Factors	Internal Event
14	Russia/Caspian Shortfall	Regional Shortfall
15	Russia/Caspian Duration	Regional Duration
16	Africa Internal Factors	Internal Event
17	Africa Shortfall	Regional Shortfall
18	Africa Duration	Regional Duration
19	Latin America Internal Factors	Internal Event
20	Latin America Shortfall	Regional Shortfall
21	Latin America Duration	Regional Duration

UNDERLYING EVENT SCALES AND PROBABILITIES

The influence diagram of Figure 1 contains two underlying events: Middle East Conflict and Russia with West Conflict. For both underlying events and regional events, the influence diagram shows an influencing arc pointing into them from Oil Price Scenarios. Later sections of this report describe these price scenarios. These three oil price scenarios (reference, low, and high) allowed experts to provide three different assessments depending upon the state of oil markets prior to a disruption. Lower oil prices might make some areas more vulnerable to greater geopolitical risks while higher oil prices might dampen these risks by providing greater financial stability within the country. Hence, there are three assessments (one for each oil price scenario) for both Middle East Conflict and Russia with West Conflict. The underlying event scale definitions and probability assessments are in Tables 5 and 6. Hybrid conflict in the second state for Russia with the West Conflict (Table 6) combines conventional warfare with irregular conflict including cyber warfare.

Table 5. Middle East Conflict: Scale and Probability Assignments

Oil Price Scenarios			1 Middle East Conflict
Ref Pr	Low Pr	High Pr	
5%	5%	15%	1. Minimal conflicts and relatively stable geopolitics (like prior to Arab Spring)
20%	20%	10%	2. Domestic persistent unrest (political/religious/ethnic) in many Middle East and North Africa countries
35%	30%	35%	3. Unrest in many middle east countries including strife with insurgent groups (like current)
25%	30%	20%	4. Growing unrest/strife in many Middle Eastern countries combined with: a) may or may not close key choke points, key facilities and/or b) Coordinated supply reductions across countries (including embargoes or
15%	15%	20%	5. Interstate military conflict between standing governments in the Middle East a) may or may not close key choke points, key facilities, supply regions b) 2 or more countries: e.g. Saudi Arabia vs. Iran, Iran vs. Iraq, Russia vs. West, possible U.S./Israeli involvement

Table 6. Russia with West Conflict: Scale and Probability Assignments

Oil Price Scenarios			12 Russia with West Conflict
Ref	Low Pr	High Pr	
1%	1%	1%	1. No conflict
74%	64%	64%	2. Only hybrid* conflict between Russia and any other nation (like current)
20%	30%	30%	3. Conflict between Russia and only Non-NATO Nation (s)
5%	5%	5%	4. Conflict between Russia and Nato Nation

INTERNAL EVENT SCALES AND PROBABILITIES

The influence diagram in Figure 1 contains five internal factors for each of the following regions in the risk assessment framework:

1. Saudi Arabia
2. Other Persian Gulf
3. Africa
4. Latin America
5. Russia and Caspian States

After the experts brainstormed a set of factors that could lead to an oil disruption, they organized them into factors that were unique to each region. From these factors, regional influence diagrams were developed to represent the range of factors that could influence supply disruptions. These regional influence diagrams, shown in Appendix B, served as the basis for developing 4 or 5-level constructed scales. Each level on the scale described a state of the world for that region in the next 10 years, from most stable (level 1) to least stable (level 4 or 5). The scales were created to be mutually exclusive and collectively exhausted, so that there would be no overlap between the scales and the scales covered the entire range of reasonable futures that could be anticipated. When these criteria are met, the probabilities assigned to the levels on each scale will sum to 100%.

As with the underlying events, the regional internal events are influenced by Oil Price Scenarios (reference, low, and high) and therefore there are three assessments for each of these internal events. The internal event scale definitions and probability assessments are in Tables 7-11.

Table 7. Saudi Internal Factors

2 Saudi Internal Factors

Oil Price Scenarios			
Ref Pr	Low Pr	High Pr	
40%	30%	50%	1. Continued acceptance of royal family, and insulation from regional instability, no major policy-driven outages, Aramco maintains high operating standards
20%	25%	15%	2. Major policy-driven temporary reduction in oil production
15%	15%	15%	3. Significant but temporary infrastructure problem from attack or technical failure and/or isolated conflict that results in attacks on infrastructure without profound internal implications
15%	15%	15%	4. Regional conflict with neighbors combined with internal political crisis, failed infrastructure and/or sabotage which is difficult to fix
10%	15%	5%	5. Full domestic instability

Table 8. Other Persian Gulf Internal Factors

3 Other Persian Gulf Internal Factors

Oil Price Scenarios				
Ref Pr	Low Pr	High Pr		
35%	25%	45%	1.	Stable regional oil output, Iraq attracts sufficient investment, Iranian agreement holds, and no major policy-driven outages
10%	10%	5%	2.	Major policy-driven temporary reduction in oil production
20%	25%	20%	3.	Significant but temporary infrastructure problem from attack or technical failure and/or isolated conflict that results in attacks on infrastructure without profound internal implications
20%	25%	15%	4.	One or more significant regional actors becomes failed states that disrupt production and exports
15%	15%	15%	5.	Regional conflict with neighbors combined with internal political crisis, failed infrastructure and/or sabotage which is difficult to fix, constraining access to Strait of Hormuz

Table 9. Africa Internal Factors

16 Africa Internal Factors

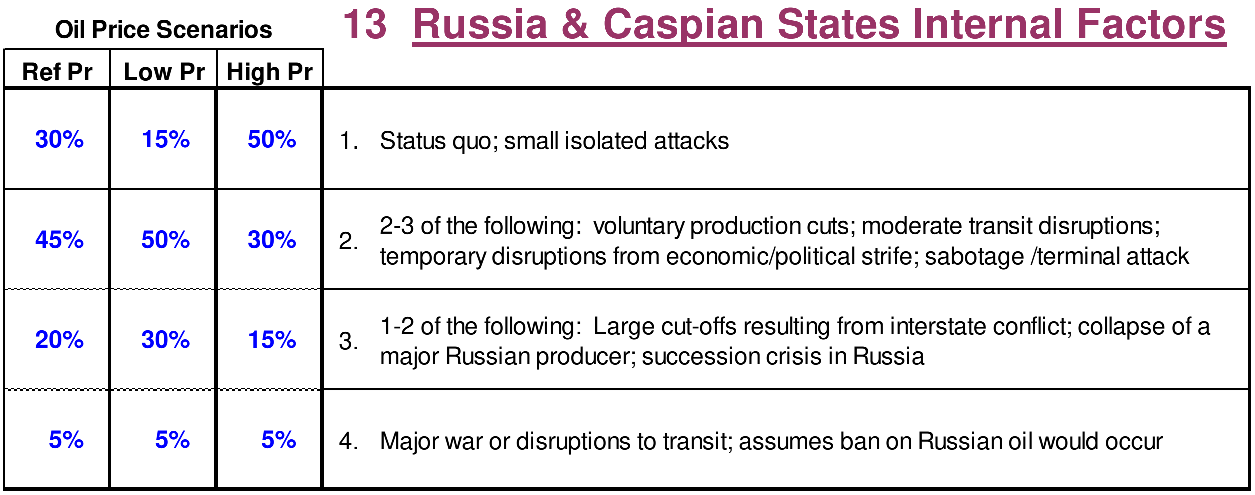
Oil Price Scenarios				
Ref Pr	Low Pr	High Pr		
5%	1%	15%	1.	Relative regional stability, limited small attacks/piracy/technical failures; countries/companies remain solvent; moderate labor unrest and operational accidents
70%	80%	70%	2.	In 1-2 countries, internal conflict and/or aggressive borderless entities targeting oil infrastructure (e.g., ISIS, MEND)
15%	4%	10%	3.	Interstate conflict between 2 countries with significant on shore production resulting in damaging assets (e.g., Libya, Egypt); fiscal failure of one or more countries and/or companies
10%	15%	5%	4.	Widespread unrest in large region (Arab Spring 2); widespread attacks against oil infrastructure; toppling of governments; failed state (s)

Table 10. Latin America Internal Factors

19 Latin America Internal Factors

Oil Price Scenarios				
Ref Pr	Low Pr	High Pr		
40%	1%	54%	1.	Relative regional stability; limited small attacks/technical failures; countries/companies remain solvent
50%	64%	40%	2.	Some sanctions imposed; disruptive labor unrest and substantial technical/operational accidents; fiscal challenges for national oil companies
5%	25%	5%	3.	Interstate conflict between 2 countries with significant on shore production resulting in damaging assets (e.g., Venezuela, Columbia) and/or fiscal failure of one or more countries and/or companies
5%	10%	1%	4.	Widespread unrest leading to region-wide Pan-American social upheaval; widespread attacks against oil infrastructure

Table 11. Russia and Caspian States Internal Factors



13 Russia & Caspian States Internal Factors

Oil Price Scenarios				
Ref Pr	Low Pr	High Pr		
30%	15%	50%	1.	Status quo; small isolated attacks
45%	50%	30%	2.	2-3 of the following: voluntary production cuts; moderate transit disruptions; temporary disruptions from economic/political strife; sabotage /terminal attack
20%	30%	15%	3.	1-2 of the following: Large cut-offs resulting from interstate conflict; collapse of a major Russian producer; succession crisis in Russia
5%	5%	5%	4.	Major war or disruptions to transit; assumes ban on Russian oil would occur

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. To assist the experts in the assessment, we defined the four states using ranges to help them clarify their thoughts in the assessment exercise, and then simplified the ranges according to the percentages in Table 12.

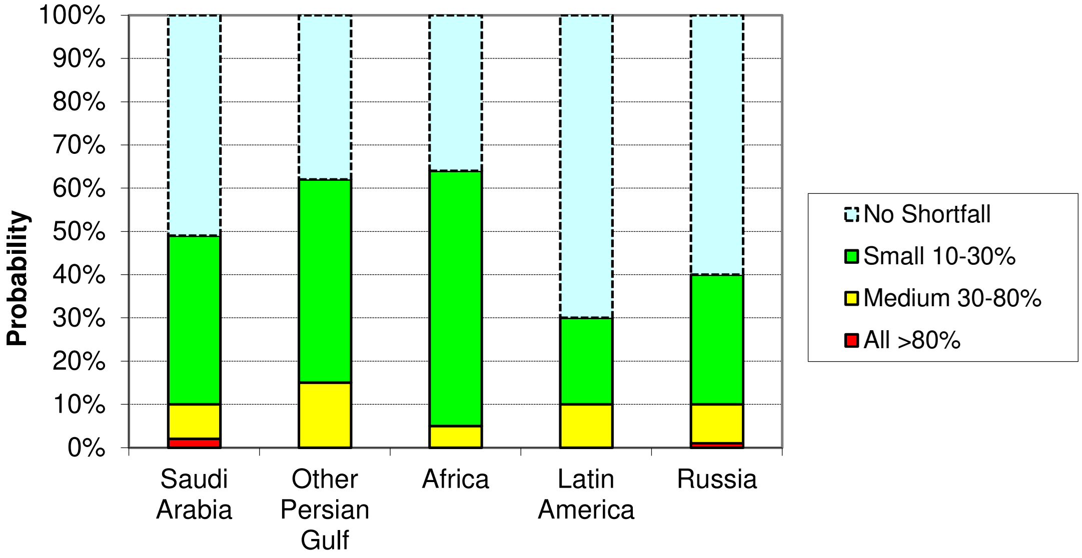
Table 12. Shortfall Definitions

Amount of Shortfall	Definition	Percentage Used in Analysis
None	None (<10%)	0%
Small	Small (10-30%)	20%
Medium	Medium (30-80%)	50%
All	All (>80%)	90%

To calculate the total size of a disruption, we multiplied the percent of supply disrupted by the study team's 2020 estimate for production in the region disrupted. We did not assess the specific time of a disruption, only whether a disruption occurs at any time in the 10-year period 2016-2025. The year 2020 was used as a representative year to estimate the amount of oil production at the time of a disruption.

Estimating the probabilities for the shortfall scale in each region is complex and multi-dimensional 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 amounts and probabilities by region, combining the individual conditioned assessments and the weighting of the underlying events, is shown in Figure 2.

Figure 2. Percent of Supply Disrupted in All Regions



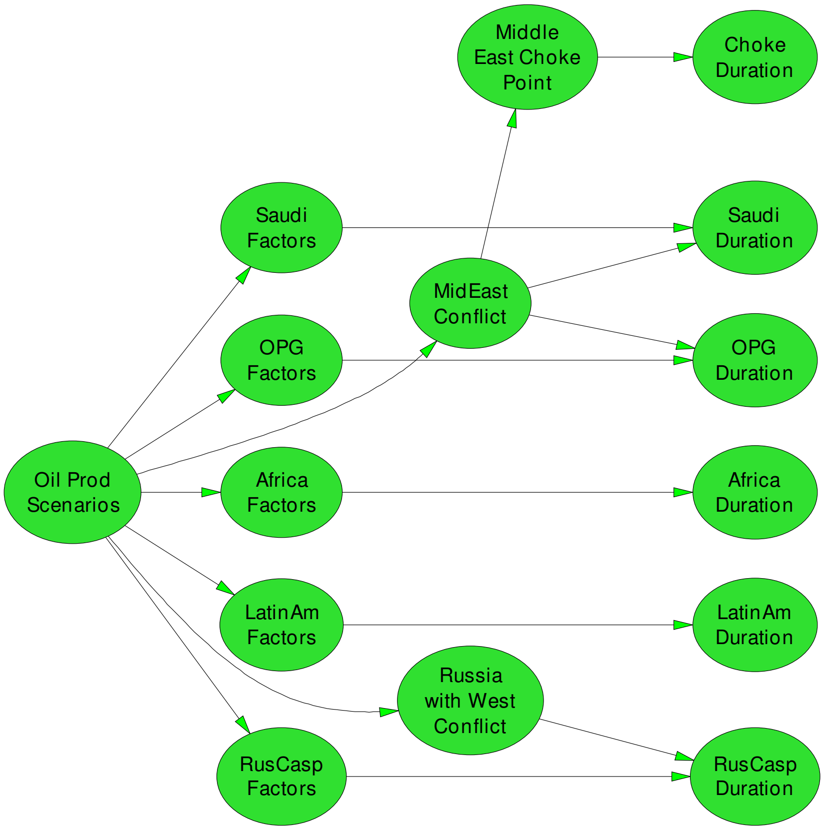
For Saudi Arabia, this chart indicates that there is a 51% chance that no disruption will occur (taking all factors into account, including Saudi Internal Affairs and Middle East Conflict). Furthermore, the chance of a disruption of 10-30% of capacity is 39%, the chance of a mediumsized disruption (30-80% of capacity) is 8%, and the chance of a complete disruption of Saudi capacity is 2%.

A similar interpretation can be read from the chart for the other four regions. Latin America has the highest probability of no disruption (70%) and Africa the lowest (36%). In Other Persian Gulf, Africa, and Latin America the chance for a complete disruption is nearly zero, and it is 1% and 2% in Russia and Saudi Arabia, respectively.

DURATION SCALES AND PROBABILITIES

The duration of a disruption could either be short (1-6 months), long (6-18 months), or very long (more than 18 months). The experts believed that the duration of a disruption depends on both underlying events (Middle East Conflict and Russia with West Conflict) as well as internal events. The influence diagram capturing key factors for oil disruption risks in Figure 1 did not include this relationship to reduce complexity in the diagram. The influence diagram of Figure 3 illustrates the relationships to establish the duration probabilities.

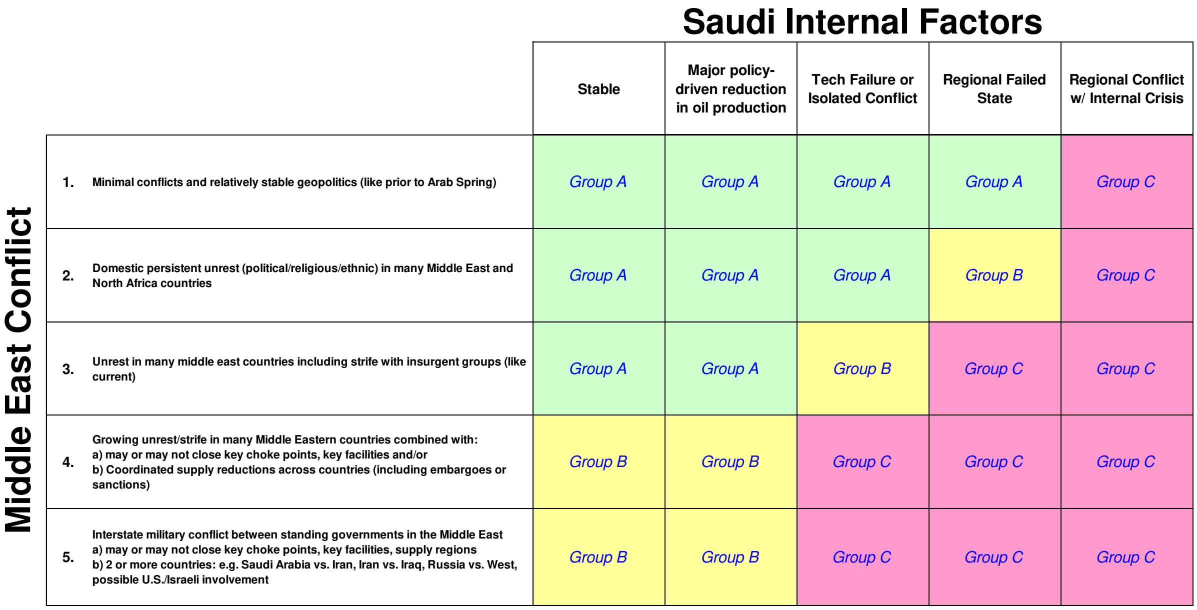
Figure 3. Influence Diagram Showing the Assessment for Duration of Disruption



The top node in Figure 3 is Choke Duration and will be described in the next section. For the 5 regions in our study, Saudi, OPG, and Russia have 2 influencing arrows pointing to the duration events, while Africa and Latin America have 1 influencing arrow. The experts were asked to identify the probability of a disruption being restored within six months, within 18 months, or beyond 18 months. For the 3 regions with 2 influencing arrows, the experts provided unique probabilities depending on the states of the predecessor nodes. For example, Figure 4 identifies 25 possible states that reflect these interrelationships for Saudi Arabia. The columns represent the 5 possible states for Saudi internal conditions, and the rows represent the 5 possible states of the entire Middle East region. Each of the 25 cells in the five-by-five matrix requires a distinct probability distribution for short, long, and very long disruptions.

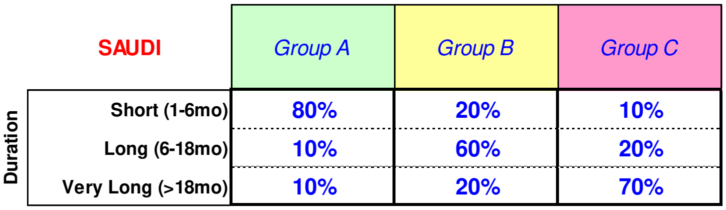
To simplify the assessment task for Saudi and Other Persian Gulf, the 25 distinct scenarios were classified into three groups, with each group being treated as having a similar likelihood of duration. Group A is characterized by mostly shorter disruptions, Group C by longer disruptions, and Group B by a mixture of short and long durations. The probability assignments for each group are shown in Figure 5. A similar structure for Other Persian Gulf is shown in Figures 6 and 7. The Russia-Caspian region has 16 distinct scenarios as each of its predecessor nodes had 4 states. For this region, as well as the Africa and Latin America, rather than create groups, we asked the experts for their distributions directly for each conditioning event.

Figure 4. Group Assignments for Saudi Duration



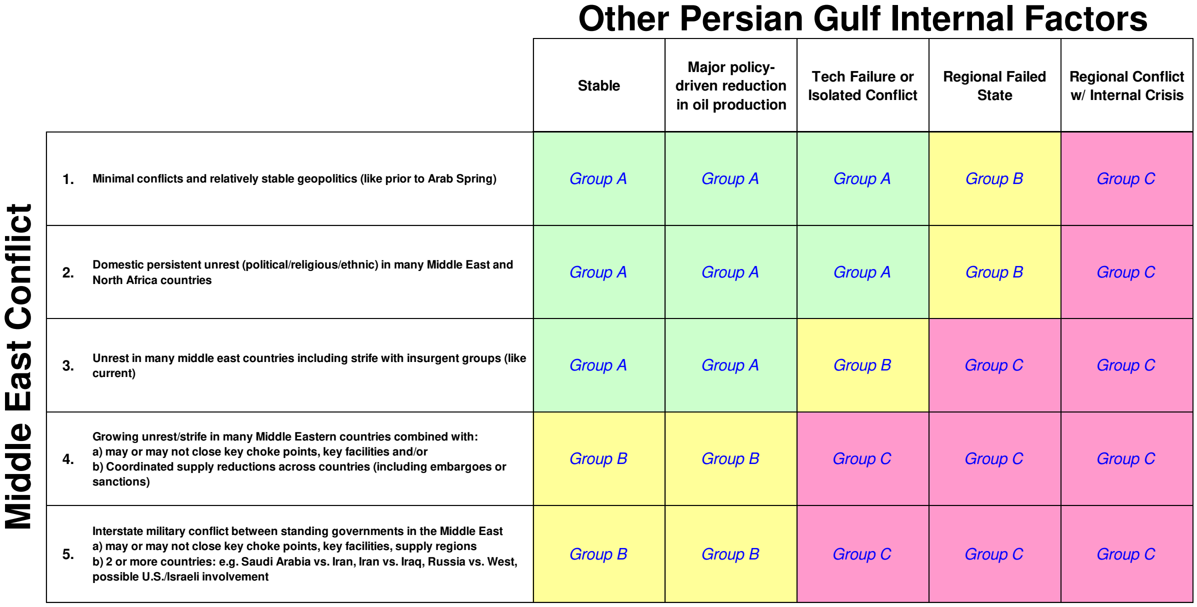
Middle East Conflict		Saudi Internal Factors				
		Stable	Major policy-driven reduction in oil production	Tech Failure or Isolated Conflict	Regional Failed State	Regional Conflict w/ Internal Crisis
1.	Minimal conflicts and relatively stable geopolitics (like prior to Arab Spring)	*Group A*	*Group A*	*Group A*	*Group A*	*Group C*
2.	Domestic persistent unrest (political/religious/ethnic) in many Middle East and North Africa countries	*Group A*	*Group A*	*Group A*	*Group B*	*Group C*
3.	Unrest in many middle east countries including strife with insurgent groups (like current)	*Group A*	*Group A*	*Group B*	*Group C*	*Group C*
4.	Growing unrest/strife in many Middle Eastern countries combined with: a) may or may not close key choke points, key facilities and/or b) Coordinated supply reductions across countries (including embargoes or sanctions)	*Group B*	*Group B*	*Group C*	*Group C*	*Group C*
5.	Interstate military conflict between standing governments in the Middle East a) may or may not close key choke points, key facilities, supply regions b) 2 or more countries: e.g. Saudi Arabia vs. Iran, Iran vs. Iraq, Russia vs. West, possible U.S./Israeli involvement	*Group B*	*Group B*	*Group C*	*Group C*	*Group C*

Figure 5. Disruption Duration Probabilities for Saudi



	SAUDI	*Group A*	*Group B*	*Group C*
Duration	Short (1-6mo)	80%	20%	10%
	Long (6-18mo)	10%	60%	20%
	Very Long (>18mo)	10%	20%	70%

Figure 6. Group Assignments for Other Persian Gulf Duration

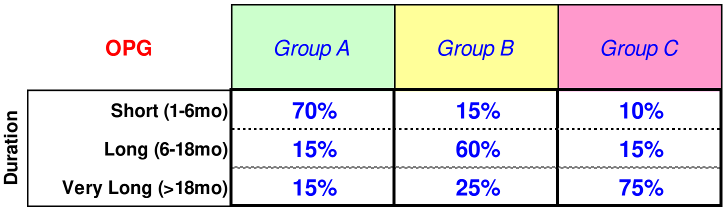


Other Persian Gulf Internal Factors

Middle East Conflict

		Stable	Major policy-driven reduction in oil production	Tech Failure or Isolated Conflict	Regional Failed State	Regional Conflict w/ Internal Crisis
1.	Minimal conflicts and relatively stable geopolitics (like prior to Arab Spring)	Group A	Group A	Group A	Group B	Group C
2.	Domestic persistent unrest (political/religious/ethnic) in many Middle East and North Africa countries	Group A	Group A	Group A	Group B	Group C
3.	Unrest in many middle east countries including strife with insurgent groups (like current)	Group A	Group A	Group B	Group C	Group C
4.	Growing unrest/strife in many Middle Eastern countries combined with: a) may or may not close key choke points, key facilities and/or b) Coordinated supply reductions across countries (including embargoes or sanctions)	Group B	Group B	Group C	Group C	Group C
5.	Interstate military conflict between standing governments in the Middle East a) may or may not close key choke points, key facilities, supply regions b) 2 or more countries: e.g. Saudi Arabia vs. Iran, Iran vs. Iraq, Russia vs. West, possible U.S./Israeli involvement	Group B	Group B	Group C	Group C	Group C

Figure 7. Disruption Duration Probabilities for Other Persian Gulf



	OPG	Group A	Group B	Group C
Duration	Short (1-6mo)	70%	15%	10%
	Long (6-18mo)	15%	60%	15%
	Very Long (>18mo)	15%	25%	75%

The durations for Africa, Latin America, and Russia are less complex which allowed for the duration probabilities to be assessed directly. For Africa and Latin America they are conditioned on the internal factors for that region and are shown in Figures 8 and 9. For Russia and Caspian States, they depend on both internal factors and the underlying event "Russia with West Conflict" and are shown in Figure 10.

Figure 8. Disruption Duration Probabilities for Africa

18 Africa Duration

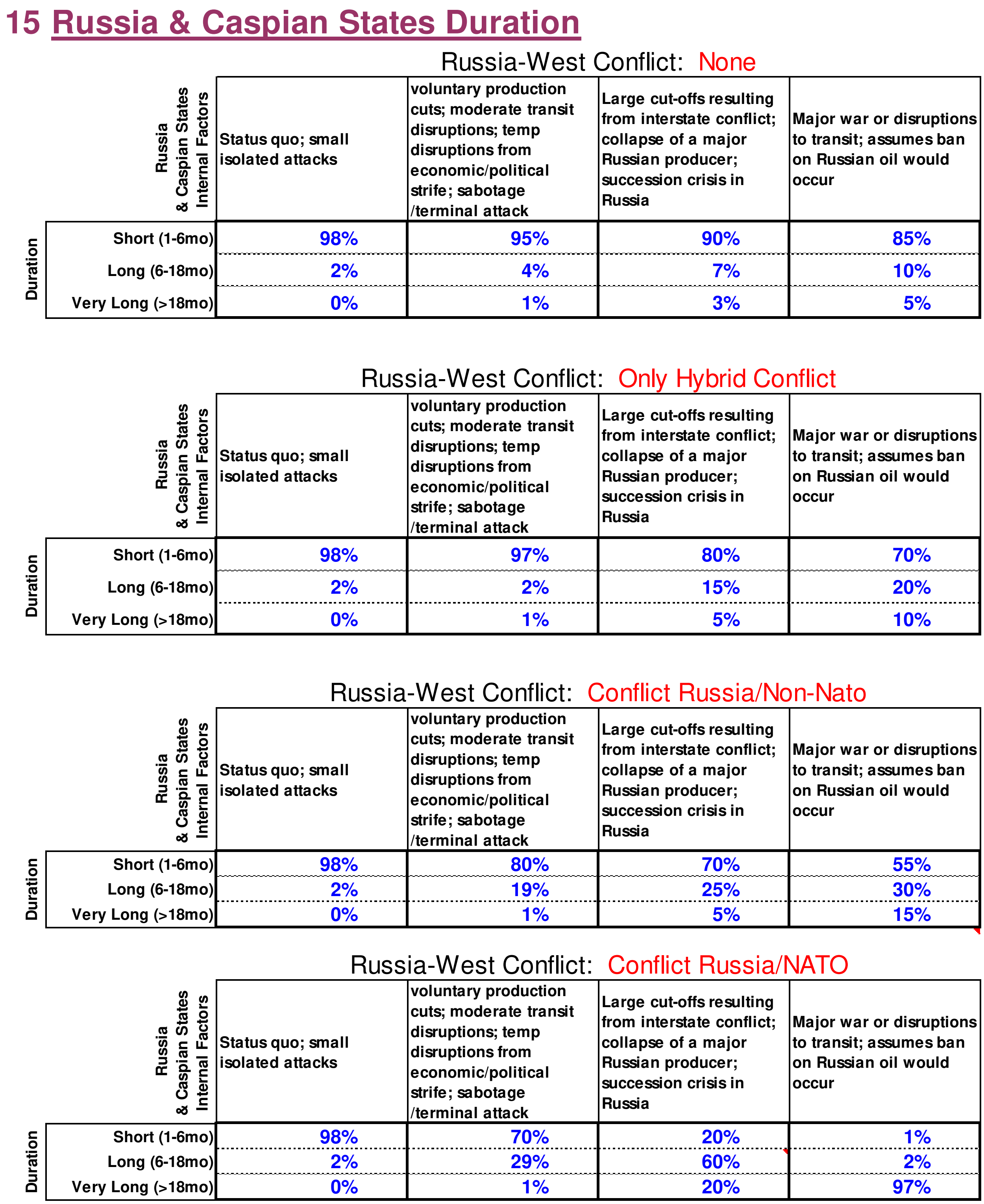
Duration \ Africa Internal Factors	Relative regional stability, limited small attacks/piracy/technical failures; countries/companies remain solvent; moderate labor unrest	internal conflict and/or aggressive borderless entities targeting oil infrastructure	Interstate conflict with damaged assets; fiscal failure	Widespread unrest in large region (Arab Spring 2); toppling of governements; failed state (s)
Short (1-6mo)	80%	50%	20%	10%
Long (6-18mo)	10%	30%	30%	20%
Very Long (>18mo)	10%	20%	50%	70%

Figure 9. Disruption Duration Probabilities for Latin America

21 Latin America Duration

Duration \ Latin America Internal Factors	Relative regional stability; limited small attacks/technical failures; countries/companies remain solvent	Some sanctions imposed; disruptive labor unrest and substantial technical/operational accidents; fiscal challenges for national oil companies	Interstate conflict between 2 countries with significant on shore production resulting in damaging assets (e.g., Venezuela, Columbia) and/or fiscal failure of one or more countries and/or companies	Widespread unrest leading to region-wide Pan-American social upheaval; widespread attacks against oil infrastructure
Short (1-6mo)	80%	50%	30%	10%
Long (6-18mo)	10%	30%	30%	30%
Very Long (>18mo)	10%	20%	40%	60%

Figure 10. Disruption Duration Probabilities for Russia and Caspian States



15 Russia & Caspian States Duration

Russia-West Conflict: None

	Russia & Caspian States Internal Factors	Status quo; small isolated attacks	voluntary production cuts; moderate transit disruptions; temp disruptions from economic/political strife; sabotage /terminal attack	Large cut-offs resulting from interstate conflict; collapse of a major Russian producer; succession crisis in Russia	Major war or disruptions to transit; assumes ban on Russian oil would occur
Duration	Short (1-6mo)	98%	95%	90%	85%
	Long (6-18mo)	2%	4%	7%	10%
	Very Long (>18mo)	0%	1%	3%	5%

Russia-West Conflict: Only Hybrid Conflict

	Russia & Caspian States Internal Factors	Status quo; small isolated attacks	voluntary production cuts; moderate transit disruptions; temp disruptions from economic/political strife; sabotage /terminal attack	Large cut-offs resulting from interstate conflict; collapse of a major Russian producer; succession crisis in Russia	Major war or disruptions to transit; assumes ban on Russian oil would occur
Duration	Short (1-6mo)	98%	97%	80%	70%
	Long (6-18mo)	2%	2%	15%	20%
	Very Long (>18mo)	0%	1%	5%	10%

Russia-West Conflict: Conflict Russia/Non-Nato

	Russia & Caspian States Internal Factors	Status quo; small isolated attacks	voluntary production cuts; moderate transit disruptions; temp disruptions from economic/political strife; sabotage /terminal attack	Large cut-offs resulting from interstate conflict; collapse of a major Russian producer; succession crisis in Russia	Major war or disruptions to transit; assumes ban on Russian oil would occur
Duration	Short (1-6mo)	98%	80%	70%	55%
	Long (6-18mo)	2%	19%	25%	30%
	Very Long (>18mo)	0%	1%	5%	15%

Russia-West Conflict: Conflict Russia/NATO

	Russia & Caspian States Internal Factors	Status quo; small isolated attacks	voluntary production cuts; moderate transit disruptions; temp disruptions from economic/political strife; sabotage /terminal attack	Large cut-offs resulting from interstate conflict; collapse of a major Russian producer; succession crisis in Russia	Major war or disruptions to transit; assumes ban on Russian oil would occur
Duration	Short (1-6mo)	98%	70%	20%	1%
	Long (6-18mo)	2%	29%	60%	2%
	Very Long (>18mo)	0%	1%	20%	97%

CHOKE POINTS

Conflicts which restrict shipping lanes can lead to a significant disruption. The experts discussed four possible choke points and their likelihood of leading to a significant disruption. After discussion and simplification, they agreed to consider only one choke point, the Strait of Hormuz, as a significant source of disruption. Although the Straight currently sees 17 MMBD of crude oil through these shipping lanes, the experts believed that Saudi Arabia can easily divert close to 2.8 MMBD of crude oil through the East-West Pipeline to bypass Hormuz. The group limited the largest disruption size possible to 8 MMBD because the producers could find other means of diverting the oil. A partial disruption of 4 MMBD is also a possibility, so the scale for a Middle East Choke Point through the Strait of Hormuz is 0, 4, and 8 MMBD, respectively.

The likelihood of a choke point disruption depends on the state of Middle East Conflict. With minimal conflict, the experts believed that there was virtually no possibility for a choke point disruption as shown in Figure 11. With levels 2-4 on the Middle East Conflict scale, the probability of a choke point disruption is very low. However, with a level 5 on this scale, where the Middle East has interstate conflicts between standing governments, the probability of a 4 MMBD and 8 MMBD disruption is 60% and 20%, respectively.

The amount of total oil flowing through the Strait of Hormuz is approximately 7 MMBD from Saudi Arabia and 10 MMBD from Other Persian Gulf. Known offsets that are likely be used are approximately 2.8 MMBD within Saudi Arabia through the East-West Pipeline and 0.9 MMBD in the United Arab Emirates via the Abu Dhabi Crude Oil Pipeline.[2] After excluding these offsets, the Saudi Arabian net flows through this choke point were 32% of the total and the Other Persian Gulf net flows were 68%. We assumed that if a choke point disruption occurs, the disruption will be from both regions proportionally.

An important assumption for incorporating a choke point disruption into the overall risk assessment is the connection with shortfalls in Saudi Arabia and Other Persian Gulf. It is possible that both a choke point disruption and a regional disruption occur simultaneously, but if the regional disruption is severe it is likely that there will be no choke point disruption since very little oil will be flowing through the shipping lanes. To avoid double counting, if Saudi or Other Persian Gulf has a shortfall of "Medium" (50% of production) or "All" (90% of production) then the choke point disruption will not occur. For all other situations, the choke point disruptions are added to the shortfall amounts consistent with the logic for adding shortfall amounts from the five regions in the study[3].

For choke point durations, the experts believe that the large choke point disruption of 8 MMBD would be either short or long at 50% probabilities, but never very long. For a 4 MMBD choke point disruption, they assigned a 75% probability to a short duration and 25% to a long duration.

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[2] U.S. Energy Information Administration, "World Oil Transit Chokepoints," November 2014, http://www.eia.gov/beta/international/regions-topics.cfm?RegionTopicID=WOTC.

[3] The logic for adding shortfalls across regions relied on the assumption that if a shortfall occurred, it was equally likely to be at any time during the 10-year period.

Figure 11. Choke Point Probabilities based on Middle East Conflict

	Choke		
0	4MMBD	8 MMBD	
100%	0%	0%	1. Minimal conflicts and relatively stable geopolitics (like prior to Arab Spring)
99%	1%	0%	2. Domestic persistent unrest (political/religious/ethnic) in many Middle East and North Africa countries
95%	5%	0%	3. Unrest in many middle east countries including strife with insurgent groups (like current)
85%	14%	1%	4. Growing unrest/strife in many Middle Eastern countries combined with: a) may or may not close key choke points, key facilities and/or b) Coordinated supply reductions across countries (including embargoes or sanctions)
20%	60%	20%	5. Interstate military conflict between standing governments in the Middle East a) may or may not close key choke points, key facilities, supply regions b) 2 or more countries: e.g. Saudi Arabia vs. Iran, Iran vs. Iraq, Russia vs. West, possible U.S./Israeli involvement

EXCESS CAPACITY SCALES AND PROBABILILITES

If a disruption of oil supplies occurs, it may be offset completely or partially by excess capacity. The experts agreed that significant excess capacity is only available from Saudi Arabia and Other Persian Gulf sources. Saudi excess capacity could be between 0.5 and 2 MMBD while Other Persian Gulf would have only 0.5 MMBD. The experts provided estimates on likelihoods of various amounts available at the time of a disruption as shown in Table 13.

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 Table 13, we can compute the probability distribution on excess capacity available (Figure 12). The stair step line in this figure is the probability of having this amount of spare capacity or more. The vertical line at 0.4 MMBD is the probability-weighted average of all possible amounts of excess capacity available.

Table 13. Excess Capacity Amount and Likelihood

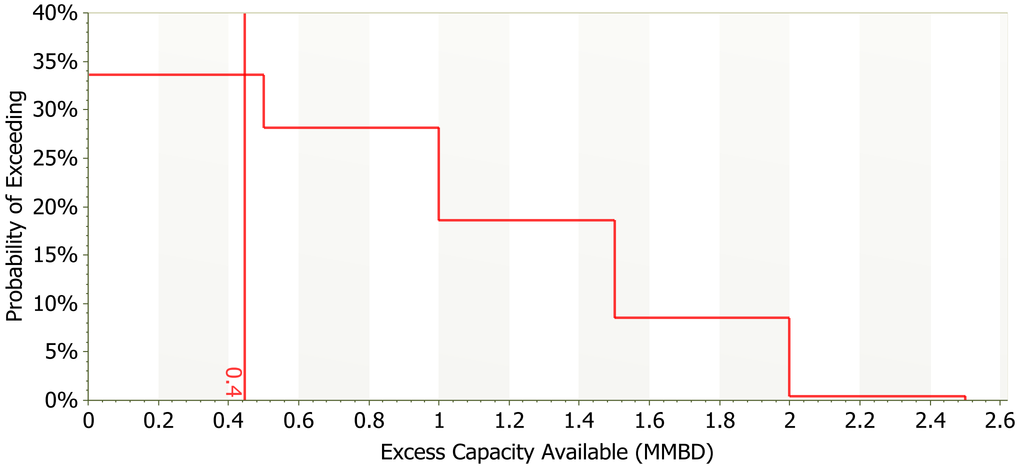
Saudi Excess Capacity

MMBD	Probability
0	25%
0.5	5%
1	25%
1.5	25%
2	20%

Other Persian Gulf Excess Capacity

MMBD	Probability
0	85%
0.5	15%

Figure 12. Probability Distribution of Net Excess Capacity Available



OIL PRODUCTION SCENARIOS AND PROBABILITIES

A number of assessments depended on the state of the oil market as characterized by a low, reference, or high price scenario. The experts did not seek to arrive at a consensus view regarding the validity or probability of oil price forecasts, as this discussion is outside the scope of the oil disruption risk assessment. We did, however, help the experts think about how their assessment of risks might change for different oil price paths. In making their baseline assessments, experts thought about a price path that recovered gradually from their recent levels after the 2014 oil price collapse. As an alternative, we asked them to think about a high oil price path where they recovered more quickly from these levels. A third alternative called the low price case allowed them an opportunity to evaluate risks when the recovery in oil prices was much more modest. The oil price scenarios were qualitative guidelines rather than precise numerical forecasts. Within the 10-year risk assessment time frame 2016-2025, we chose the year 2020 as a representative year for all three oil production scenarios (Table 14). Although we did not ask the experts to evaluate the likelihood that each oil price case would exist, reporting our results about overall risks requires that some probabilities be assigned. The study group organizers assigned probabilities of 30%, 40%, and 30% to the high, reference, and low price scenarios, respectively.

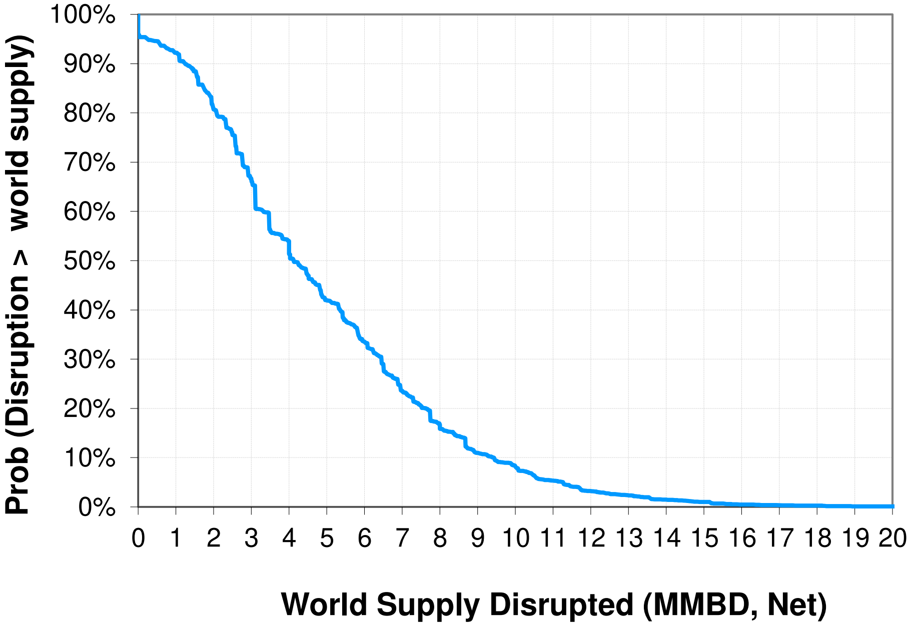
Table 14. Oil Production Scenarios

	Production 2020 (MMBD)		
	Reference	Low Price	High Price
World	97.62	99.40	94.81
Middle East	27.12	30.38	22.59
Saudi Arabia	11.62	13.02	9.68
Other Persian Gu	15.49	17.36	12.91
Africa	8.50	9.25	7.64
Latin America	6.06	6.05	5.93
Russia & Caspian	13.89	13.77	14.60
Other	42.05	39.94	44.06
OPEC Share	28%	31%	24%
World Price ($/B)	97	69	150

SECTION 6. RESULTS

The detailed probability data obtained from the experts are listed in Appendix C. This information was entered into DPL software,[4] a state-of-the-art decision and risk analysis package. To obtain summary information, we calculated the disruption size for all combinations of event states (millions of scenarios) and weighted each scenario by its likelihood of occurrence.

Figure 13. Probability of an Oil Disruption Lasting 1-6 Months



The scenario-probability pairs are summarized and displayed in an Excess Probability graph shown for all disruptions in Figure 13. 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. For example, the data point at 5 MMBD and 42% can be described as a 42% chance that a 5 MMBD disruption or larger will occur at least one time in the 10-year time frame 2016-2025. It is very likely that a disruption greater than 2 MMBD will occur (81%). However, it is unlikely that disruptions greater than 15 MMBD will occur (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 34% (probability of >5 is 42%, probability of >10 is 8%, difference is 42%-8% = 34%). The graph shows a larger weighting for the range between 2-8 MMBD by the steep drop in the curve in these regions.

The distribution in Figure 13 is a combination of events in each of five regions. We can examine the contribution of each region to the overall distribution by showing the results for one region at a time, assuming no disruptions in the other regions. Figures 14-16 shows each region

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[4] DPL decision tree and influence diagram software by Syncopation Software

independently on the same excess probability graph. Other Persian Gulf and Africa regions have the larger probabilities of disruption (for disruptions less than 1 MMBD) than Latin America or Russian and Caspian States. Saudi Arabia is in the middle at about 50% chance that some oil will be disrupted. The probability of any disruption and the probability of 2 MMBD or greater disruption are summarized in Table 15.

Table 15. Probability of a Disruption by Region

	Probability of a Disruption: > 0 MMBD	Probability of a Disruption: > 2 MMBD
Africa	62%	5%
Other Persian Gulf	61%	51%
Saudi Arabia	48%	37%
Russian / Caspian States	40%	32%
Latin America	28%	8%

Figure 14. Comparison of Short-Duration Disruptions by Region

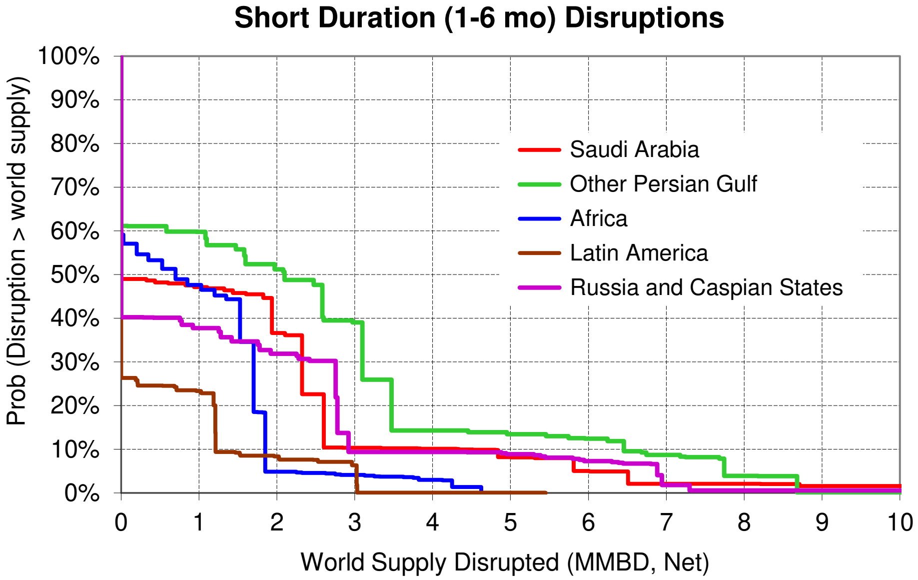


Figure 15. Comparison of Long-Duration Disruptions by Region

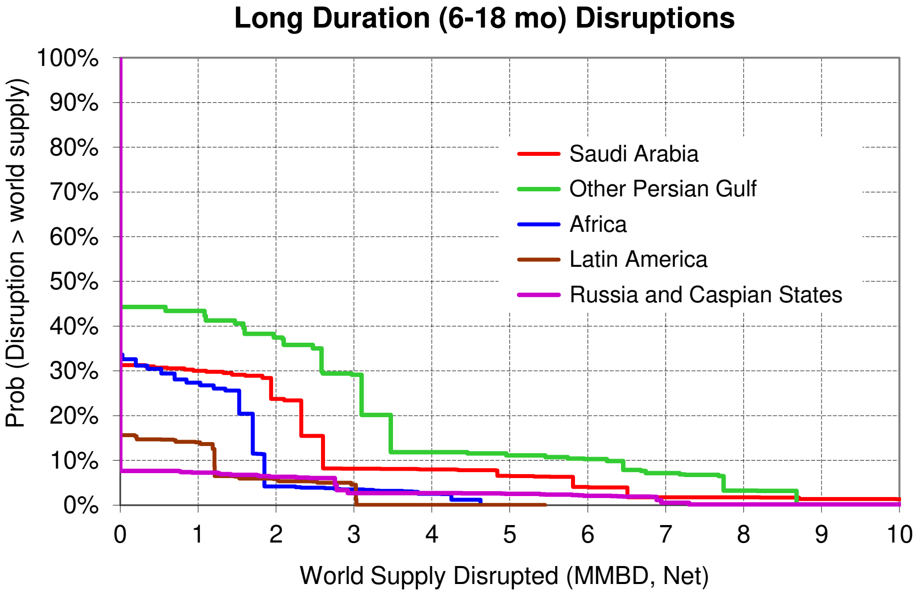


Figure 16. Comparison of Very Long-Duration Disruptions by Region

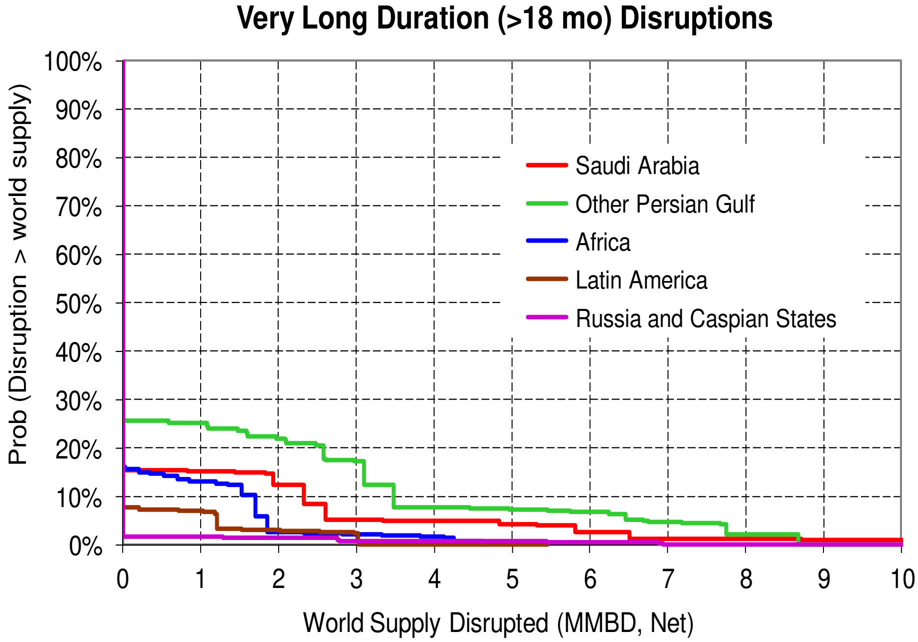
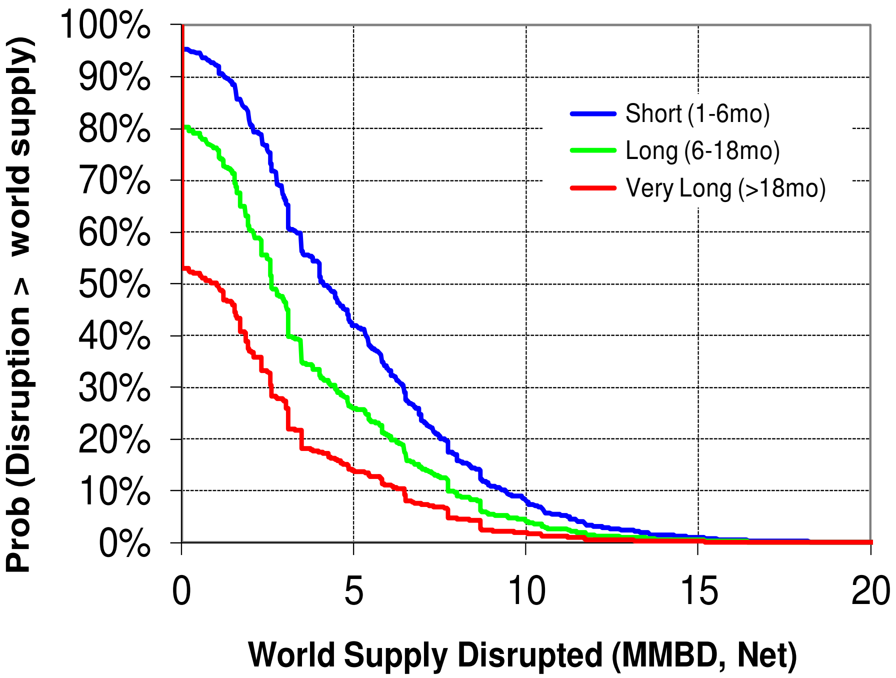


Figure 17. Probability of a Disruption for All Durations



Combining all regions together, we can show all three durations on the same curve (Figure 17), 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 16), which highlights that Other Persian Gulf is the most significant contributor to overall risk for a disruption of any duration.

Table 16. Probability of a Disruption > 2 MMBD by Region and Duration

Probability of a Disruption > 2 MMBD

	Saudi Arabia	Other Persian Gulf	Africa	Latin America	Russia /Caspian	All Regions
Short (1-6mo)	37%	51%	5%	8%	32%	81%
Long (6-18mo)	24%	37%	4%	6%	6%	63%
Very Long (>18mo)	12%	22%	3%	3%	1%	37%

The distributions in Figures 14-16 compare regional probability distributions by duration. We can also contrast the durations of a disruption for each region as shown in Figure 18. For the Russia/Caspian States, the shorter duration disruptions are much more likely than longer durations. The likelihood of very long durations in Other Persian Gulf are at least double that of other regions. Figure 19 summarizes the proportion of short, long, and very long disruptions by each region.

Figure 18. Probability of a Disruption by Region for Each Duration

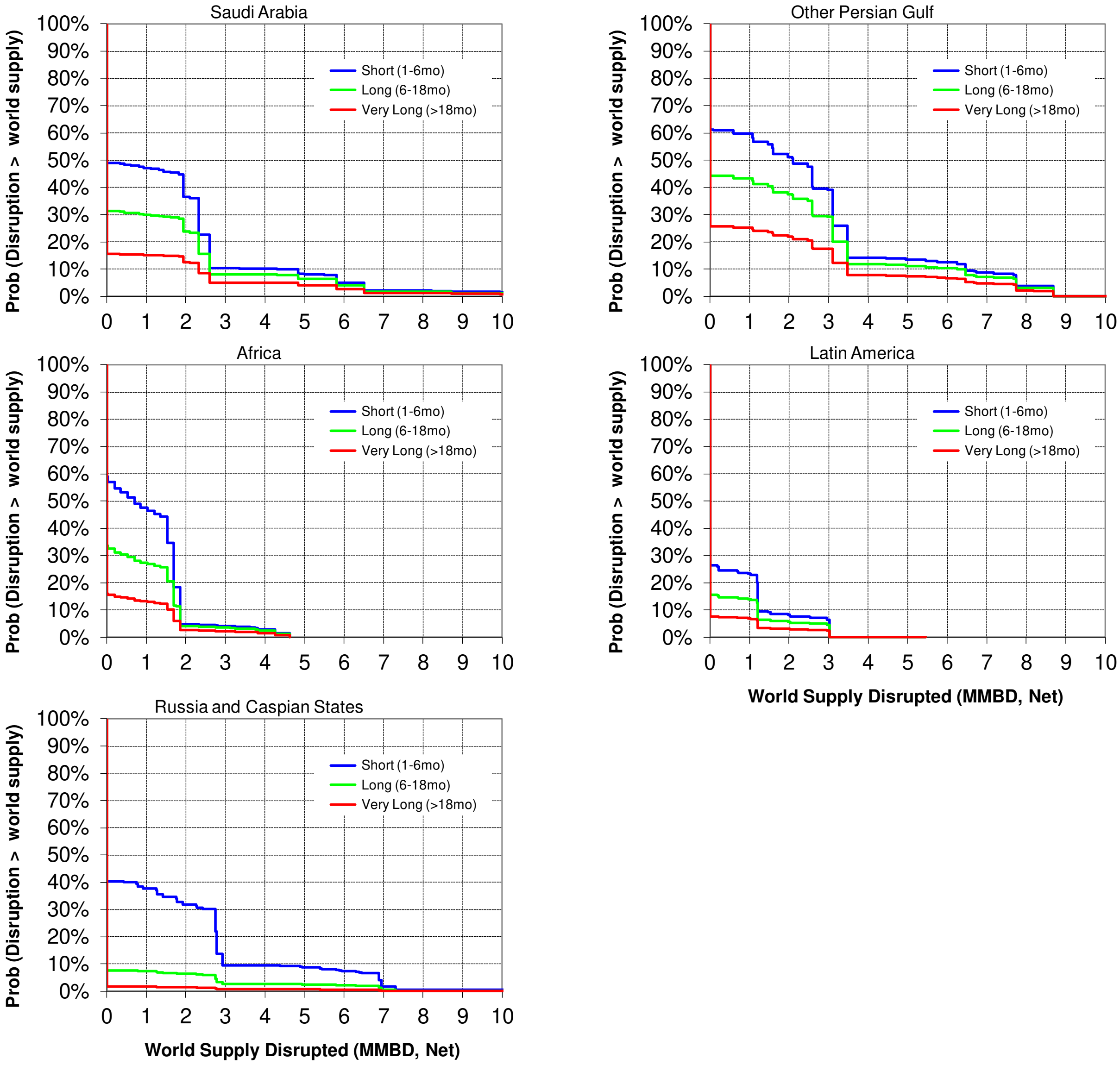
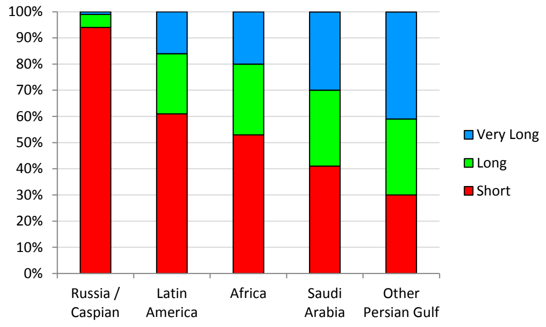
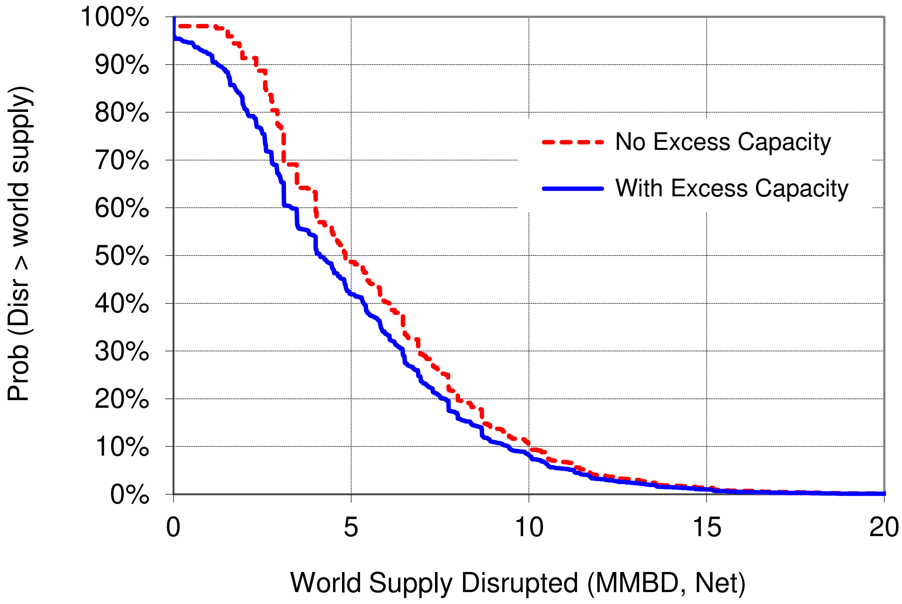


Figure 19. Comparison of Duration Probabilities by Region



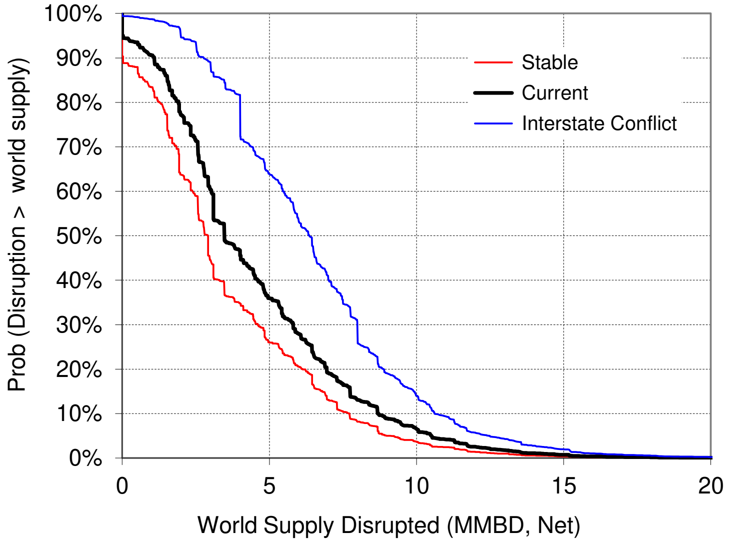
A sensitivity analysis testing the impact of offsets to the risk assessment is shown in Figure 20. With no excess capacity, a flat region between 0-2 MMBD represents a near certainty that a disruption of this magnitude will occur in the next 10 years. The effect of including excess capacity tends to shift the distribution to the left by roughly 2/3 MMBD, which represents the average of the amount of excess capacity available.

Figure 20. Sensitivity to Removing Excess Capacity



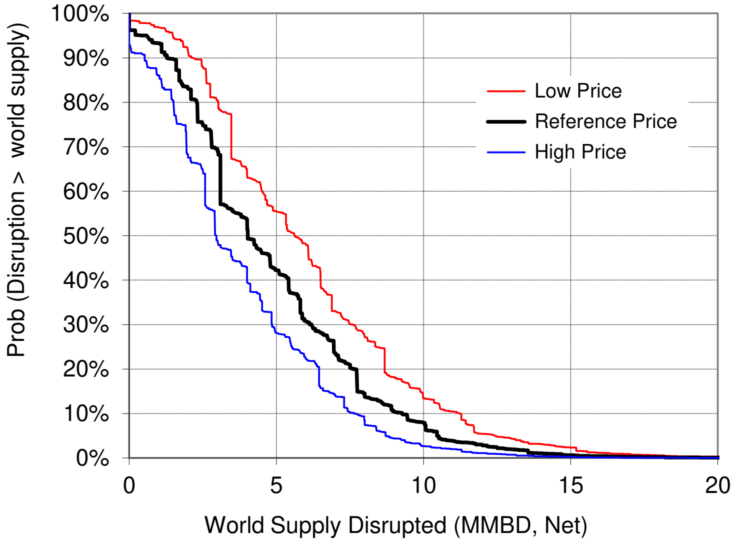
We examined the sensitivity to Middle East conflict, as it was believed that an underlying event affecting multiple regions together may have a significant impact on disruption risks. Figure 21 contrasts the current state in the Middle East (Unrest in many Middle Eastern countries including strife with insurgent groups) with two separate cases representing the extreme conditions in the Middle East: stable conditions like prior to the Arab Spring, and interstate military conflict between standing governments of two or more countries. At 5 MMBD or greater, the probability varied from 26% under stable conditions to 64% under interstate conflict conditions, 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 21. Sensitivity to Middle East Conflict Event



In the prior risk assessment, oil price scenarios were used to estimate different production amounts which were then multiplied by the percent shortfall to determine the disruption size. In this assessment, oil price scenarios took a more significant role in estimating probabilities for internal factors and underlying events. Figure 22 shows the sensitivity of the three oil price scenarios to the overall probability of a disruption. Higher oil prices result from lower production amounts from the five relatively unstable regions evaluated in this study. In addition, they lower probabilities of a disruption relative to the reference price scenario. The opposite trend occurs for the low price scenario. At 5 MMBD, the probabilities vary from 28% to 55%, showing that changes in oil price can alter the viewpoint about oil disruption risks. Lower oil price paths make net disruptions of any given size more likely.

Figure 22. Sensitivity to Oil Price Scenario



SECTION 7. COMPARISON WITH PRIOR STUDIES

Besides the current study, four formal oil disruption risk assessments have been conducted in the past 25 years for the purposes of SPR sizing considerations: the 1990 DOE Interagency study relying on statistical parameter estimation, the 1996 and 2005 EMF studies incorporating expert judgment and decision analytic methods, and the 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 2005 EMF study with the current 2015 EMF study, both of which rely on the same underlying methodology and processes. The DOE sponsors specifically requested the EMF to sponsor this risk assessment due to their interest in how the change in world events have influenced the conclusions of the 2005 EMF study, and because of their belief in the validity and usefulness of the approach.

In general, this panel of energy security experts has concluded that current world events and energy markets have increased the likelihood of oil disruptions since 1996 but demonstrated a similar risk profile compared to the 2005 period. The probability of a disruption in the current study is very modestly lower than in 2005 for disruptions less than 7 MMBD. The likelihood of a disruption for 7 MMBD or more is roughly equivalent in the two studies.

We start by discussing changes in scope of the two studies, then compare and contrast the key inputs on event probabilities, shortfall probabilities, duration probabilities, and excess capacity estimates. We conclude with a discussion of overall results and a comparison with the 1996 risk assessment.

In the 2005 study, experts identified four regions that had significant risk of disruptions: Saudi, Other Persian Gulf, West of Suez, and Russia and Caspian States. In this study, there are five regions since the West of Suez region was split into Africa and Latin America. All other regions included the same countries with the exception that Mexico was added to West of Suez (now Latin America). Furthermore, an explicit consideration of choke points was added to the current framework and treated as a significant source of oil disruption risks.

Each study considered Middle East Conflict as a key underlying event that conditioned both Saudi and OPG internal assessments. The 2015 study also added Russia with West Conflict as a second underlying event, which was used to support the assessment for Russia and Caspian states regional factors, but did not have an effect on other regions. The scales for internal events for each study had four or five levels, but their definitions were adjusted 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. For example, Level 1 for Middle East Conflict in 2005 was “No conflict (any existing conflict ending quickly)” while in 2015 it is “Minimal conflicts and relatively stable geopolitics (like prior to Arab Spring).” For Level 2, the experts defined the scale in 2005 as “Limited war, including active insurgent operations, e.g., Arab/Iran - Israeli War” but the 2015 assessment has a Level 2 defined as “Domestic persistent unrest (political/religious/ethnic) in many Middle East and North Africa countries.” Although there are five levels for each study, both the descriptions of each level and the probabilities assigned to them have changed. The comparison of the likelihood of particular states between the two studies is seen in Table 17.

For both 2005 and 2015, stability in the Middle East is defined as either a level 1 or level 2 on the scale, even though there are variations in the scale definitions. The probability of stability in the Middle East has decreased 29% from 54% to 25%, assuming “No conflict and Limited Arab-Israeli war” are considered stable for Middle East Conflict in 2005 and “Minimal conflict and Growing domestic unrest” are stable for 2015. The probability of stable internal affairs for Saudi and Other Persian Gulf has remained about the same (35% - 43%). The probability of policy-driven reductions in Saudi has doubled over the past 10 years to 20%. The probability of stable internal affairs in Russia and the Caspian States has also remained consistent at about 70%, but interstate conflict has increase from 10% to 28%. Figure 23 shows a graphical comparison of stability probabilities, and for this viewpoint we have included the data from the 1996 study when relevant. On this figure, the two regions that replaced the West of Suez region from 2005 (Africa and Latin America) are shown on the far right. Also shown is the Russia with West conflict. All three of these bars have no basis to compare with prior studies.

Table 17. Comparison of Event Probabilities with Prior Studies[5]

Middle East Conflict 2005

1	No conflict	5%
2	Limited Arab-Israeli war	49%
3	Spillover to unrest	15%
4	Limited war oil producer	21%
5	Extended active war	10%

Middle East Conflict 2015

1	Minimal conflict	8%
2	Growing domestic unrest	17%
3	Growing political unrest	34%
4	Limited interstate unrest	25%
5	Wider-spread interstate conflict	16%

Saudi Internal Factors 2005

1	Stable	40%
2	Stable with cutback	10%
3	Insurgency-intermittent disruptions	30%
4	Saudi hostile to West	15%
5	Civil war - failed state	5%

Saudi Internal Factors 2015

1	Stable	39%
2	Major policy-driven reduction	21%
3	Tech failure or isolated conflict	15%
4	Reg conflict with internal crisis	15%
5	Full social rev; curtail exports	11%

OPG Internal Factors 2005

1	Stable except Iraq	23%
2	Stable except Iraq with cutback	12%
3	Civil war or succession in 1 country	50%
4	Civil war or succession in 2 countries	15%

OPG Internal Factors 2015

1	Stable	34%
2	Major policy-driven reduction	9%
3	Tech failure or isolated conflict	22%
4	Failed states	21%
5	Regional conflict w/ internal crisis	15%

Russia Internal Factors 2005

1	Stable	63%
2	Stable with cutback	7%
3	Terror attack on facility	20%
4	Insurgency or border conflict	10%

Russia Internal Factors 2015

1	Status quo; small isolated attacks	30%
2	voluntary production cuts; strife	43%
3	Interstate conflict; Russia suc crisis	23%
4	Major war; ban on Russian oil	5%

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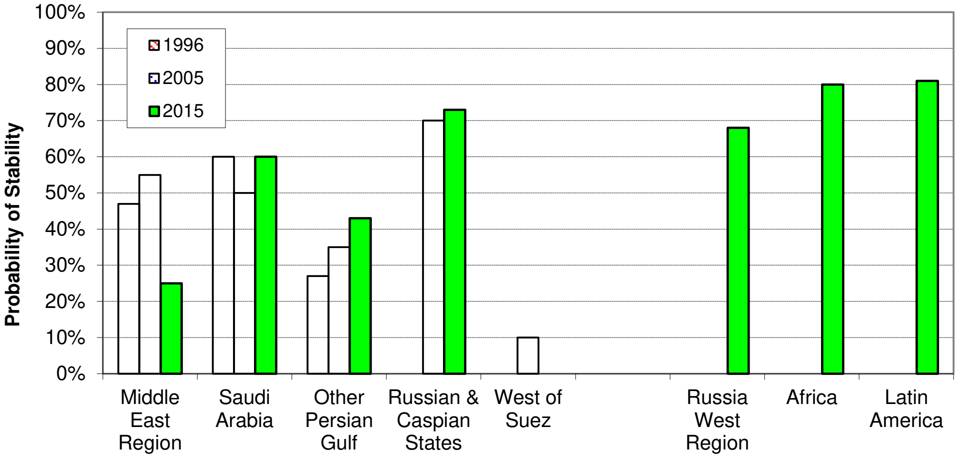
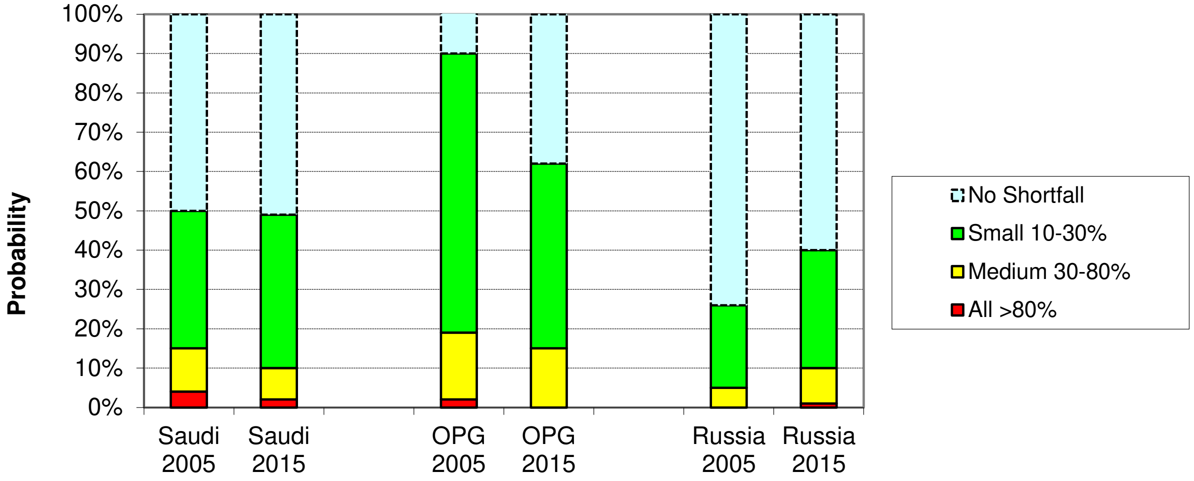
[5] The scale definitions between the 2005 and 2015 assessments are similar but not identical, so caution should be used in making a direct comparison between the two studies.

Figure 23. Comparison of Probability of Stability



The size of shortfall was estimated by the expert panel by assigning probabilities to four states (No Shortfall, Small 10-30%, Medium 30-80%, All >80%). They did this under various conditioning event assumptions (internal events and underlying events). The summary results are expressed in the bar chart of Figure 24. There is remarkable similarity in Saudi Arabia between 2005 and 2015. There is a 50% probability of no shortfall for both. The probability of disrupting all of Saudi production dropped from 4% in 2005 to 2% in 2015. For Other Persian Gulf, the probability of No shortfall or a small shortfall is 80%-85%, while the probability of no shortfall increased from 11% to 38%. In 2005, experts provided a 2% probability of all of Other Persian Gulf facilities to be disrupted, and in 2015 that probability has dropped to nearly 0%. Russia and Caspian region showed a decrease in no shortfall from 74% to 60%.

Figure 24. Comparison of Shortfall Size

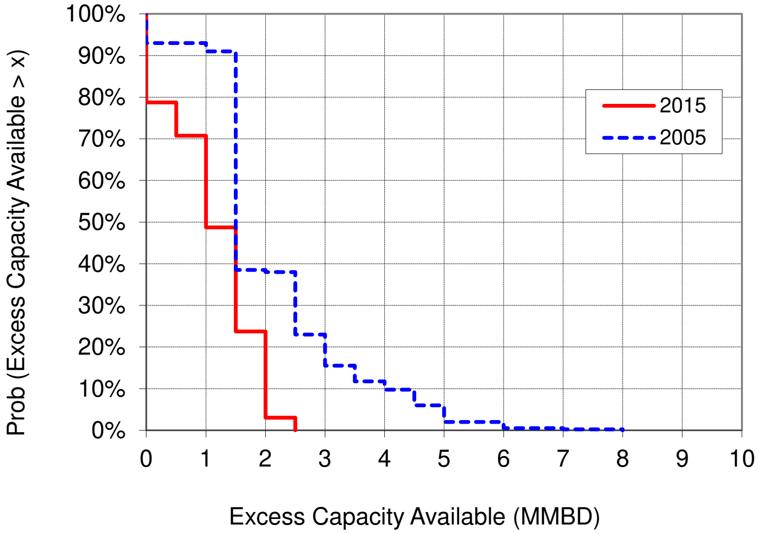


Today's excess capacity estimates have decreased by about half of the levels from 2005. Even though the experts limited the Saudi excess capacity to no more than 2 MMBD (in 2005 there was a small probability of 3 and 5 MMBD), there is a higher likelihood of small amounts of excess capacity available. This assessment by the current group of experts results in the overall average for Saudi Arabia to decrease from about 1.7 MMBD in the 2005 assessment to 1.1 MMBD available in the current study. The only other region in which excess capacity could be available is Other Persian Gulf, and it only provides a negligible amount relative to Saudi Arabia. Other Persian Gulf spare capacity has also decreased since 2005. The net effect of excess capacity available, computed by taking the probability-weighted average of all amounts, is roughly 1.1 MMBD available for both regions, down from 2.1 MMBD for both regions in 2005. The changes in excess capacity are summarized in Table 18. As in prior studies, we did not include private stock. The full cumulative probability distribution for excess capacity in Figure 25 shows the comparison of effective excess capacity for the two studies.

Table 18. Comparison of Probability of Excess Capacity

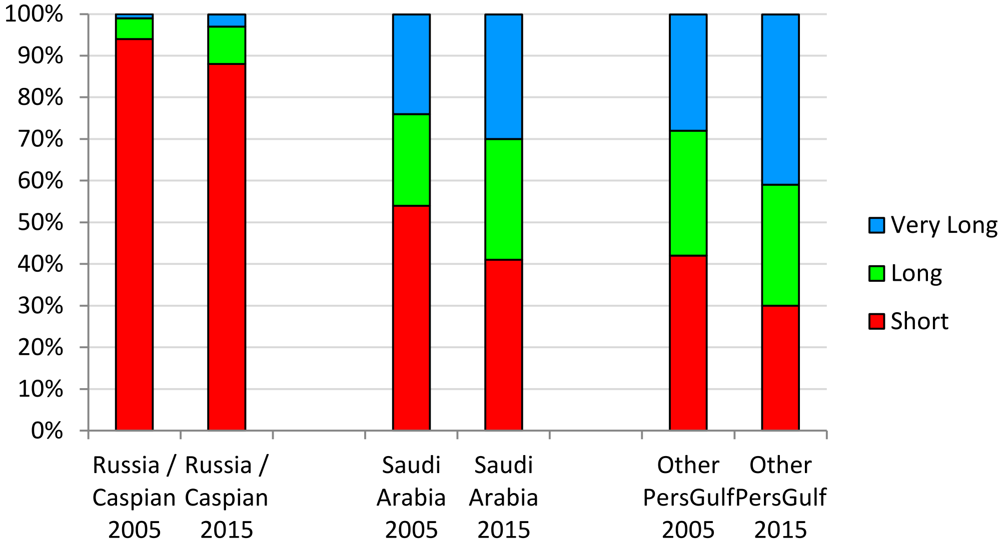
Excess Capacity Available (MMBD)	**SAUDI**		**OTHER PERSIAN GULF**	
	2005	2015	2005	2015
0	10%	25%	70%	85%
0.5		5%		15%
1.0		25%	20%	
1.5	75%	25%		
2.0		20%	5%	
2.5				
3.0	10%		5%	
3.5				
4.0				
4.5				
5.0	5%			

Figure 25. Comparison of Effective Excess Capacity



As discussed in the Results section, Russia and Caspian states have a much higher likelihood for shorter disruptions, while Other Persian Gulf states tend to have longer disruptions. In 2005, this same trend occurs as shown in Figure 26, with slightly smaller chances for very long disruptions compared to the current study.

Figure 26. Comparison of Duration Probabilities



The net effect of these changes (splitting West of Suez into two regions, adding choke points, updating event and shortfall duration probabilities, modifying excess capacity) is shown in Figures 27 and 28. The probability of a disruption in the current study is roughly 0% to 5% lower than in 2005 depending on the size of disruption considered. The probability of a disruption for 7 MMBD or more is roughly equivalent in the two studies. For the 1996 study, no direct comparison is possible with disruptions lasting longer than 18 months as only 2 durations were considered. For a more equitable comparison to the 1996 study in Figure 28, we only allowed disruptions in Saudi and Other Persian Gulf. In this comparison, the probability of any disruption in 2005 and 2015 has doubled since the 1996 study, while the probability of a 3 MMBD and 8 MMBD disruption is equivalent for all three periods (35% and 10%, respectively).

Figure 27. Comparison of Probability of Disruption for Three Study Periods

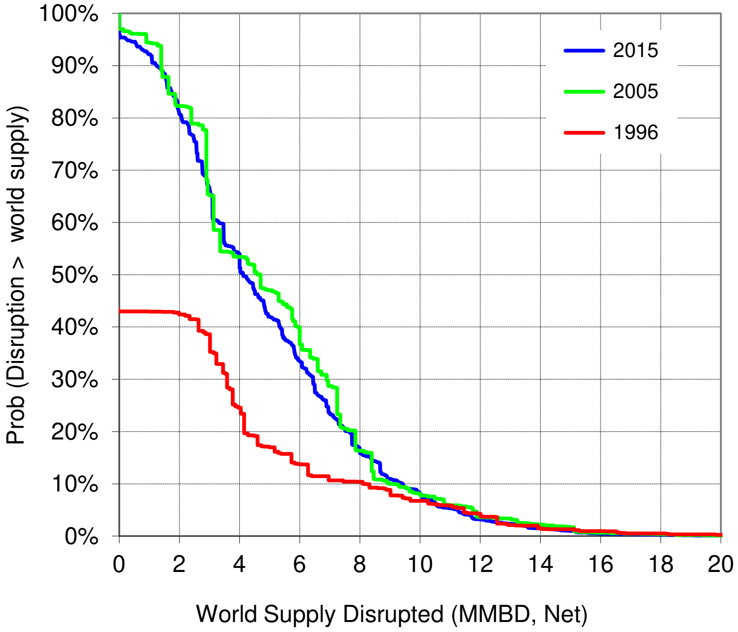
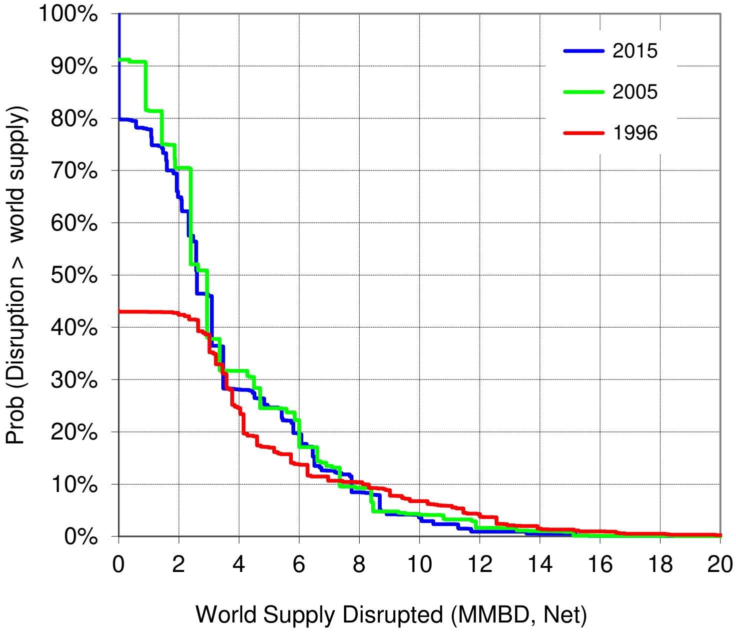


Figure 28. Comparison of Probability of Disruption for Saudi and Other Persian Gulf only



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 that were a month apart, we efficiently structured the scope of the assessment, defined variable definitions and scales, and developed inputs for 21 uncertain variables covering over 500 probability inputs. The concise tree-based algorithm employed allowed for the computation and integration of millions of combinations of scenarios, with quick updating, intuitive accounting for complex dependencies, and clear outputs to policymakers. 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 and 2005 studies, 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. We did have a small number of experts that participated in two and some in all three EMF studies, which proved very useful and promoted a more efficient dialogue and discussion about the inputs. The framework allows for a quick update of oil disruption risks if a few key events change while most of the geopolitical issues are similar. In this case, it would only require a short discussion with a few key experts, and prove particularly valuable in the near-term (1-3 years). In the long-term or with significant changes to energy security events, we recommend a similar format with two separate meetings with a diversity of experts that are conducted 2-4 weeks apart.

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. Another important extension would be to organize other expert groups and apply the same methodology to other critical events that could cause major oil supply disruptions. Experts frequently mentioned cyber security, pandemics, extreme weather and earthquakes that could arise in both geopolitically stable and unstable regions. Including these evaluations would provide a more thorough evaluation of the potential risks to world oil supplies.

SECTION 9. CONCLUSIONS

The Energy Modeling Forum at Stanford University has conducted the third assessment of future oil disruption risks in the past 20 years, each time drawing upon a common framework that has been updated to account for current geopolitical conditions relevant to significant oil disruptions. Recent changes in world events, tensions in other parts of the world, and energy markets (oil price decreases), along with the dramatic surge in North American tight oil supplies from shale formations have renewed interest by the Department of Energy (DOE) and other parties in understanding the risk of major oil disruptions. The current risk assessment was conducted through a series of two workshops in September and October of 2015 which were 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 world oil market was divided into 5 primary regions of production: Saudi Arabia, Other Persian Gulf, Africa, Latin America, and Russian / Caspian States. Taken together these regions account for 57% of the world production of 98 MMBD (as projected by the U.S. Energy Information Administration for 2020). The panel of experts also considered choke point disruptions at vulnerable shipping lanes. Not included in the assessment were disruptions from the US market and smaller global producers. Excess capacity was considered as a source to mitigate oil disruptions and therefore a primary output of the assessment is “Net Disruptions” or the total disruption less the excess capacity available.

The final results of the risk assessment convey a range of insights across the three dimensions of magnitude, likelihood, and length of a disruption.

Table 19. Probability of a Disruption by Size, Duration, and Region

	Probability of a Disruption:			
	> 0 MMBD	> 2 MMBD	> 3 MMBD	> 5 MMBD
DURATION				
Short	96%	80%	67%	42%
Long	82%	63%		
Very Long	53%	37%		
REGION				
Africa	62%			
Other Persian Gulf	61%			
Saudi Arabia	48%			
Russian / Caspian States	40%			
Latin America	28%			

In the 2005 study, experts identified four regions that had significant risk of disruptions: Saudi, Other Persian Gulf, West of Suez, and Russia and Caspian States. In this study, there are five regions since the West of Suez region was split into Africa and Latin America. All other regions included the same countries with the exception that Mexico was added to West of Suez (now Latin America). Furthermore, an explicit consideration of choke points was added to the current framework and treated as a significant source of oil disruption risks. The net effect of these changes results in a very similar probability of disruption for up to 4 MMBD and greater than 7 MMBD. Between 4-7 MMBD, the probability of a disruption in the current study is roughly 5% lower than in 2005

In general, this panel of energy security expert has concluded that current world events and energy markets have increased the likelihood of oil disruptions since 1996 but demonstrated a similar risk profile compared to the 2005 period. Moreover, their assessments indicate that lower oil price paths make net disruptions of any given size more likely.

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 policymaker. 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. To illustrate the approach taken in this study, consider an example of one adverse consequence: a 10 MMBD shortfall in production for six months in 2022. Risk assessment serves to determine what the possible adverse consequences could be and their probabilities of occurring. 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 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 approach can be time intensive.

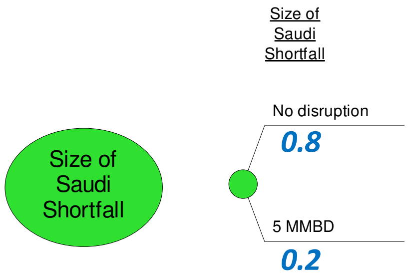
Probability assessments can be viewed as a quantitative representation of a person's knowledge. To ensure that probability assessments obtained from experts are authentic and reliable, formal procedures have been developed and were incorporated in this study. These include training on the types of biases people exhibit when facing uncertainty, interview techniques to control motivational or cognitive biases, and methods to assess multiple experts and resolve differences in opinion.

This risk assessment relied on influence diagrams to support the structuring and organizing of the complex relationships between events that lead to oil disruptions. 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. Generally, an influence diagram 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.

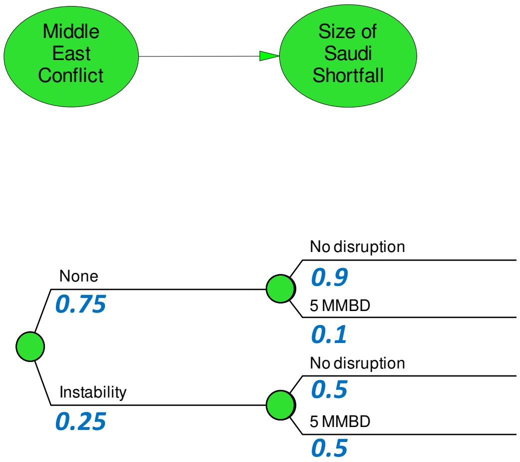
The two states both include capacity losses between 10% and 25% of total capacity. Furthermore, the collectively exhaustive condition means that all possibilities must be included. In Figure A1, we could not have the states

- 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 in the influence diagram, 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 (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 there is instability or not in the Middle East. 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

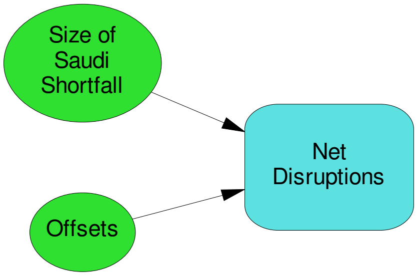


Figure A3 shows two independent events that influence the computation of the value "Net Disruption." The equation for net disruption is:

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

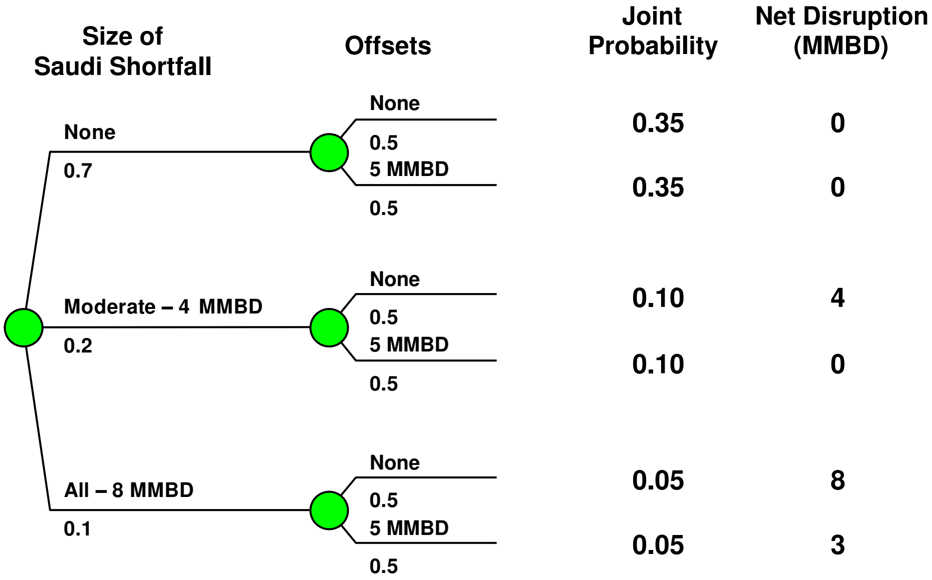
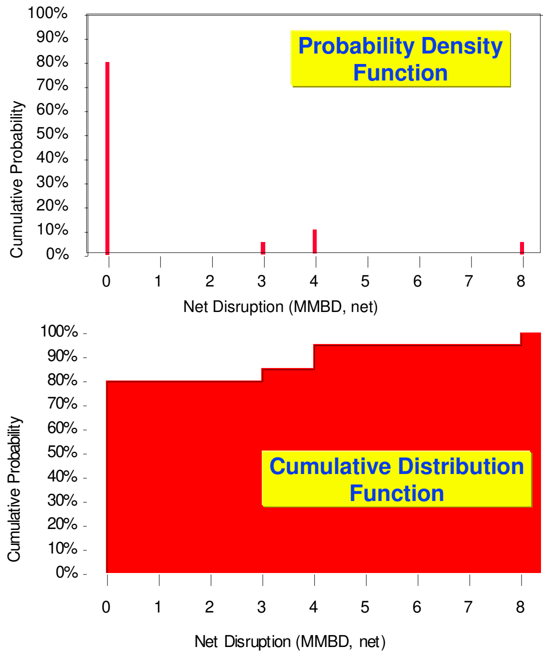


Figure A.5. Probability Density and Cumulative Distribution Function for "Net Disruption"



Each point is the probability of observing a disruption less than or equal to a disruption size x, for all values of x on the horizontal axis.

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 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%.

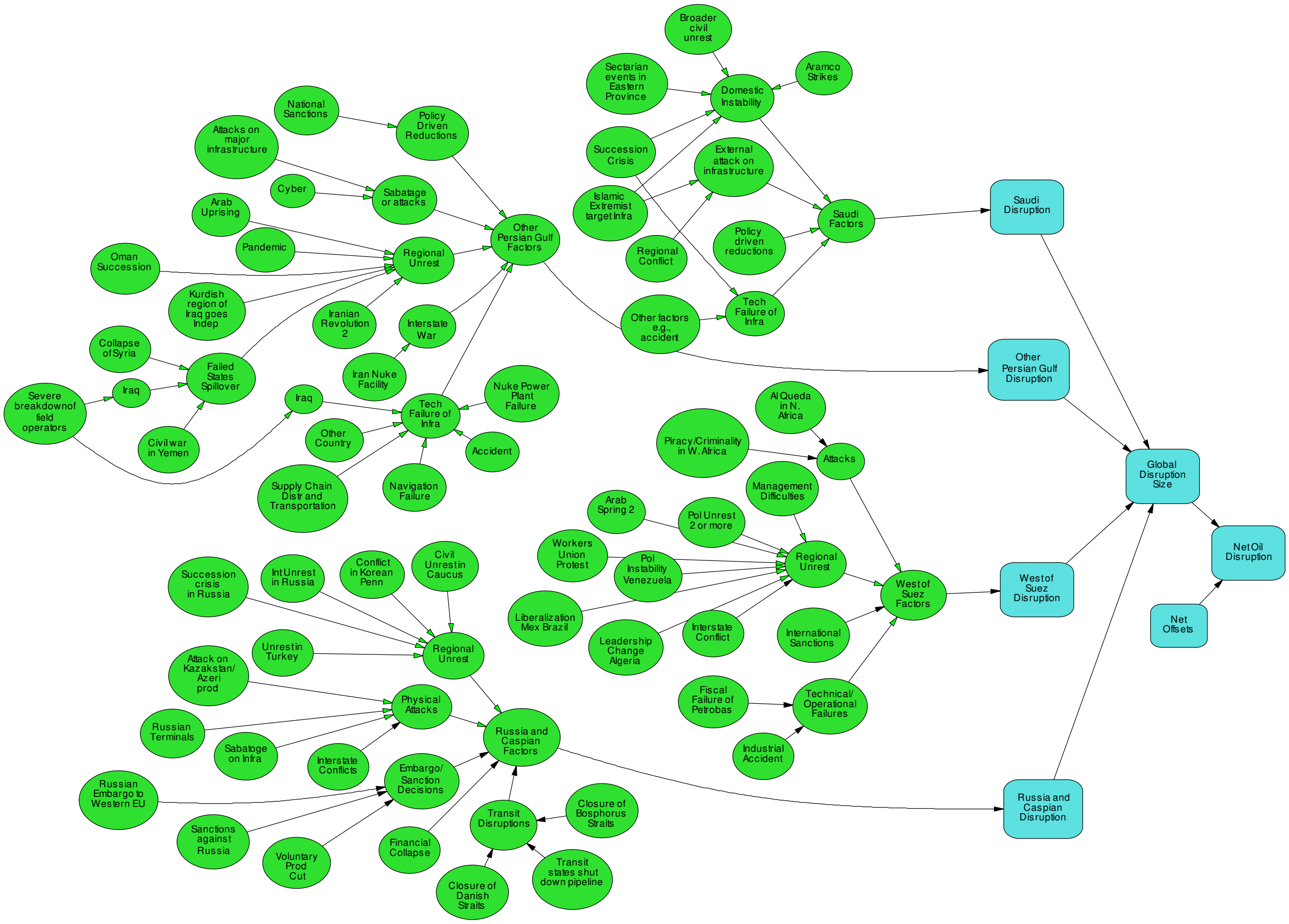
For this small problem with only two events and six scenarios, it is straightforward to translate probability assessments of uncertain events into resulting probability distributions. In the actual risk assessment with twenty one events and millions of scenarios, the cumulative probability distribution is a powerful way to compactly summarize and 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 B.1) was developed to represent the breadth of discussion and thought processes. At this stage, the decision to split West of Suez into Africa and Latin America had not yet been made, so the diagram shows only West of Suez.

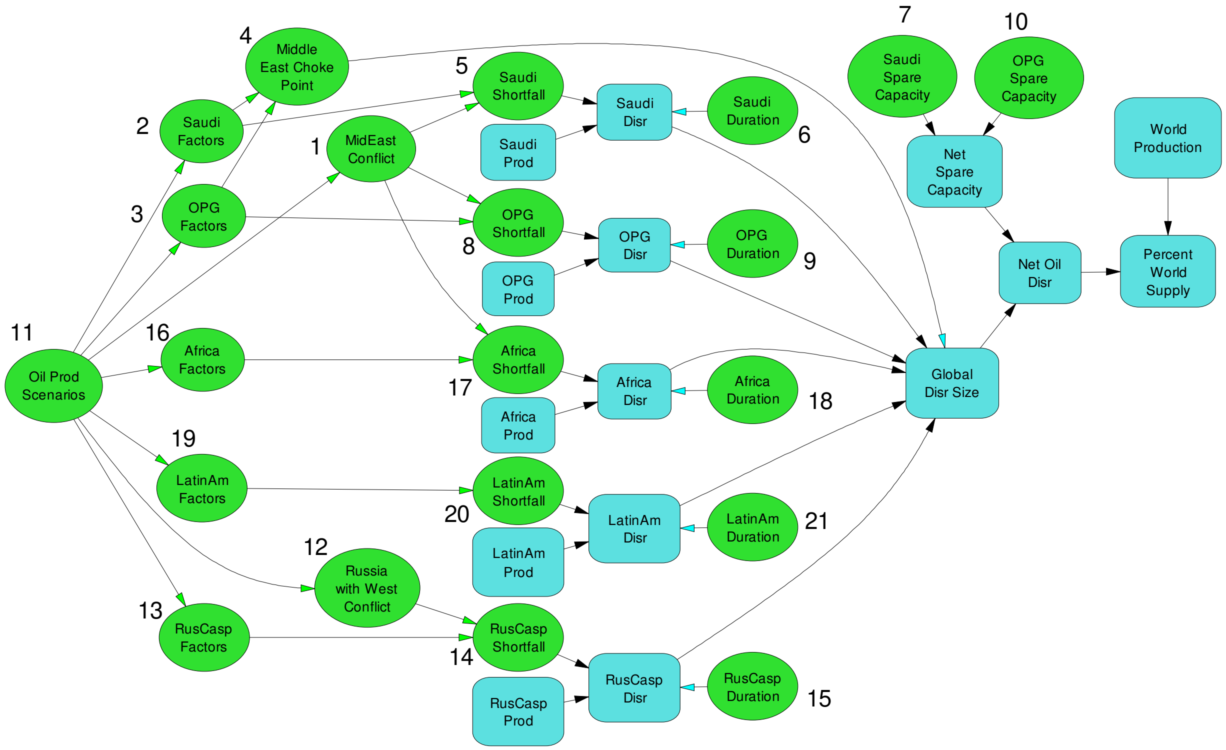
In order to simplify the assessment to a manageable size, and to reflect the key parameters that matter most to the risk assessment, the comprehensive influence diagram was simplified to the one shown in Figure 1, repeated here again in Figure B.2 for convenience.

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



The influence diagram of Figure B.2 has numbered oval nodes that represent the entire set of probabilistic inputs in the risk assessment. This appendix will define the states developed by the expert panel for each numbered node, starting with underlying events, then internal events, choke points, shortfalls, duration, excess capacity, and finally, oil production.

Figure B.2. World Oil Disruption Influence Diagram



UNDERLYING EVENTS

1. Middle East Conflict

1) Minimal conflicts and relatively stable geopolitics (like prior to Arab Spring)
2) Domestic persistent unrest (political/religious/ethnic) in many Middle East and North Africa countries
3) Unrest in many middle east countries include strife with insurgent groups (like current)
4) Growing unrest/strife in many Middle Eastern countries combined with:
   - Widespread labor unrest or terrorists (eco or cyber security) that targets oil production facilities like Abqaiq and shipping, or
   - Coordinated supply reductions across countries without interstate military conflict (including embargoes)
5) Interstate military conflict between standing governments in the Middle East
   - may or may not close key choke points, key facilities, supply regions
   - 2 or more countries: e.g. Saudi Arabia vs. Iran, Iran vs. Iraq, Russia vs. West, possible U.S./Israeli involvement

12. Russia with West Conflict

1) No Conflict
2) Only hybrid* conflict between Russia and any other nation
3) Military conflict between Russia and only non-NATO nation (s)
4) Military conflict between Russia and NATO nation

* Hybrid conflict: see page 4 of National Military Strategy of U.S., 2015

INTERNAL EVENTS

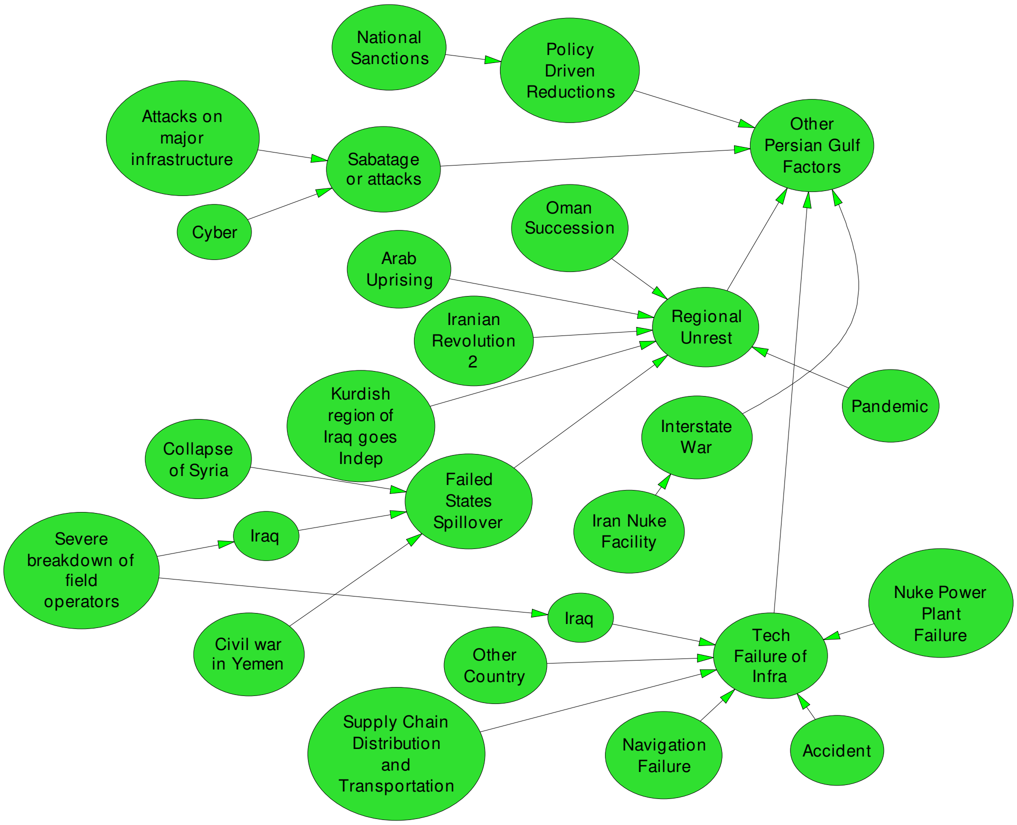
To support the development of the scales for the internal events, we split apart the events unique to each region from the comprehensive influence diagram of Figure B.1. This helped to provide a logical structure, and it also was a helpful starting point to create scale levels that accounted for the range of possible events within each region. In the following sections, we will first show the influence diagram for regional factors that could influence a disruption, and then show the associated scale for that region. The node on the right labeled “Factors” was directly assessed, while the other events were implicitly considered when the experts assigned likelihoods to the scale levels.

Figure B.3. Saudi Arabia Influence Diagram

2. "Saudi" Internal Factors

1) Continued acceptance of royal family, and insulation from regional instability, no major policy-driven outages, Aramco maintains high operating standards
2) Major policy-driven temporary reduction
3) Significant but temporary infrastructure problem from attack or technical failure and/or isolated conflict that results in attacks on infrastructure without profound internal implications
4) Regional conflict with neighbors combined with internal political crisis, failed infrastructure and/or sabotage which is difficult to fix
5) Full domestic instability resulting in curtailment of exports

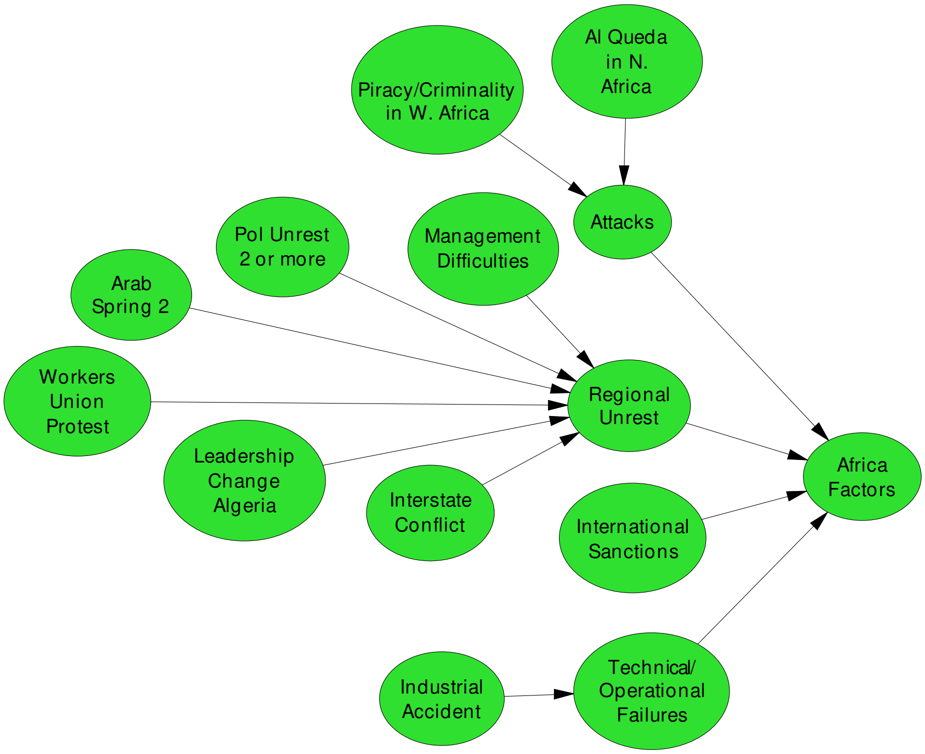
Figure B.4. Other Persian Gulf Influence Diagram



3. “Other Persian Gulf” Internal Factors

1) Stable regional oil output, Iraq attracts sufficient investment, Iranian agreement holds, and no major policy-driven outages
2) Major policy-driven temporary reduction
3) Significant but temporary infrastructure problem from attack or technical failure and/or isolated conflict that results in attacks on infrastructure without profound internal implications
4) One or more significant regional actors becomes failed states that disrupt production and exports
5) Regional conflict with neighbors combined with internal political crisis, failed infrastructure and/or sabotage which is difficult to fix, constraining access to Strait of Hormuz

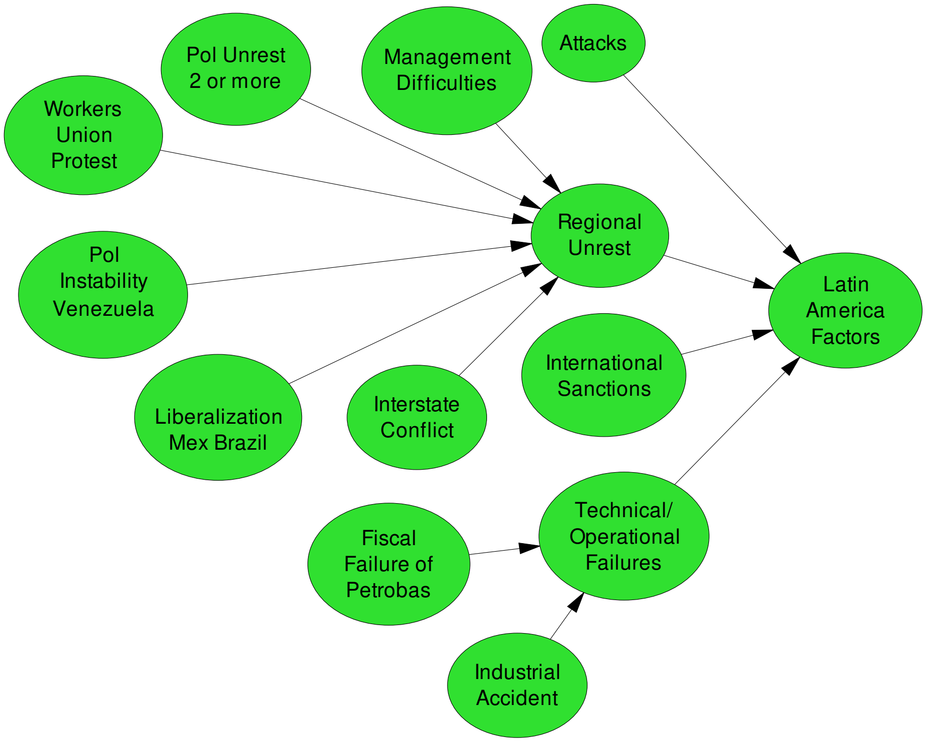
Figure B.5. Africa Influence Diagram



16. Africa Internal Factors

1) Relative regional stability, limited small attacks/piracy/technical failures; countries/companies remain solvent; moderate labor unrest and operational accidents
2) In 1-2 countries, internal conflict and/or aggressive borderless entities targeting oil infrastructure (e.g., ISIS, MEND)
3) Interstate conflict between 2 countries with significant on shore production resulting in damaging assets (e.g., Libya, Egypt); fiscal failure of one or more countries and/or companies
4) Widespread unrest in large region (Arab Spring 2); widespread attacks against oil infrastructure; toppling of governments; failed state (s)

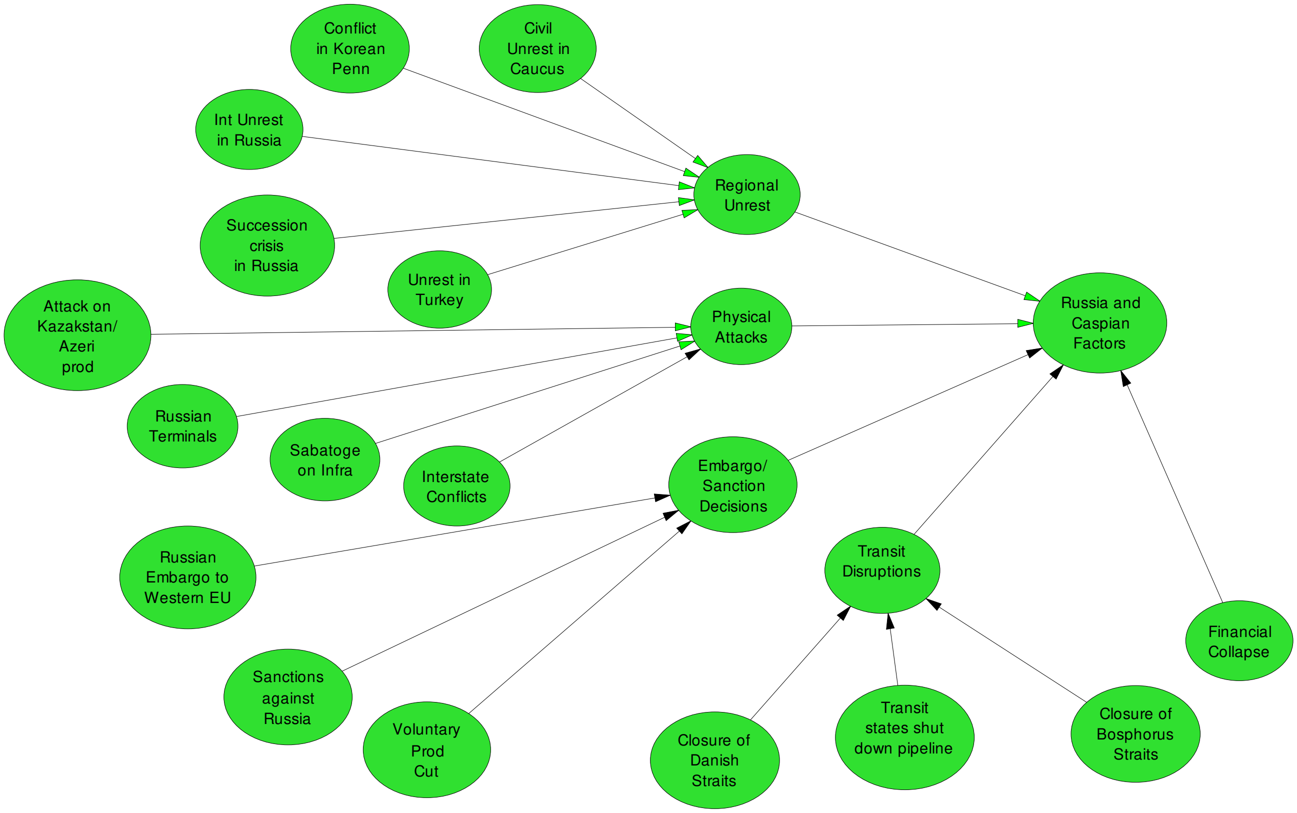
Figure B.6. Latin America Influence Diagram



19. Latin America Internal Factors

1) Relative regional stability; limited small attacks/technical failures; countries/companies remain solvent
2) Some sanctions imposed; disruptive labor unrest and substantial technical/operational accidents; fiscal challenges for national oil companies
3) Interstate conflict between 2 countries with significant on shore production resulting in damaging assets (e.g., Venezuela, Columbia) and/or fiscal failure of one or more countries and/or companies
4) Widespread unrest leading to region-wide Pan-American social upheaval; widespread attacks against oil infrastructure

Figure B.7. Russian and Caspian States Influence Diagram



13. "Russia & Caspian States" Internal Factors

1) Status quo; small isolated attacks
2) 2-3 of the following: voluntary production cuts; moderate transit disruptions; temporary disruptions from economic/political strife; sabotage /terminal attack
3) 1-2 of the following: Large cut-offs resulting from interstate conflict; collapse of a major Russian producer; succession crisis in Russia
4) Major war or disruptions to transit; assumes ban on Russian oil would occur

CHOKE POINTS

4. Middle East Choke Point

1) None: 0 MMBD
2) Partial: 4 MMBD
3) Full: 8 MMBD

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 size of the shortfall is estimated by asking the expert panel to provide the fraction of production lost in a given region. 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 U.S. Energy Information Administration for 2020, we can calculate the shortfall in MMBD. All Shortfall variables for the five regions (Saudi Arabia, Other Persian Gulf, Africa, Latin America, and Russia and Caspian States) have the same four states.

5. Shortfall (same for variables 8, 14, 17, 20)

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

DURATION

The duration of a regional shortfall, given that a disruption has occurred is either Short, Long, or Very Long. Another way to characterize the duration of a disruption is to consider 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 three states.

6. Duration (same for variables 9, 15, 18, 21)

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

EXCESS CAPACITY

7. "Saudi" Excess Capacity

The amount of excess oil production capacity (MMBD) available in Saudi Arabia midway through the 10-year period 2016 - 2025. 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) 0.5 MMBD
3) 1.0 MMBD
4) 1.5 MMBD
5) 2.0 MMBD

10. "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 2016 - 2025. 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) 0.5 MMBD

OIL PRODUCTION

11. Oil Production Scenarios

Three oil production scenarios are representative of the future uncertainty in oil price and supply. The oil price scenarios were qualitative guidelines rather than precise numerical forecasts. Within the 10-year risk assessment time frame 2016-2025, we chose the year 2020 as a representative year for all three oil capacity scenarios. The scale for this event consists of the following three levels:

1) High Price (world capacity in 2020 = 94.8 MMBD)
2) Reference Price (world capacity in 2020 = 97.6 MMBD)
3) Low Price (world capacity in 2020 = 99.4 MMBD)

APPENDIX C: PROBABILITY INPUT DATA

The risk assessment required probability inputs for 7 variable types:

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

These inputs accounted for 21 uncertain variables covering over 500 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

Oil Price Scenarios			1 Middle East Conflict
Ref Pr	Low Pr	High Pr	
5%	5%	15%	1. Minimal conflicts and relatively stable geopolitics (like prior to Arab Spring)
20%	20%	10%	2. Domestic persistent unrest (political/religious/ethnic) in many Middle East and North Africa countries
35%	30%	35%	3. Unrest in many middle east countries including strife with insurgent groups (like current)
25%	30%	20%	4. Growing unrest/strife in many Middle Eastern countries combined with: a) may or may not close key choke points, key facilities and/or b) Coordinated supply reductions across countries (including embargoes or
15%	15%	20%	5. Interstate military conflict between standing governments in the Middle East a) may or may not close key choke points, key facilities, supply regions b) 2 or more countries: e.g. Saudi Arabia vs. Iran, Iran vs. Iraq, Russia vs. West, possible U.S./Israeli involvement

Table C.2. Probabilities for Russia with West Conflict

Oil Price Scenarios			12 Russia with West Conflict
Ref Pr	Low Pr	High Pr	
1%	1%	1%	1. No conflict
74%	64%	64%	2. Only hybrid* conflict between Russia and any other nation (like current)
20%	30%	30%	3. Conflict between Russia and only Non-NATO Nation (s)
5%	5%	5%	4. Conflict between Russia and NATO Nation

Table C.3. Probabilities for Saudi Internal Events

Oil Price Scenarios			2 Saudi Internal Factors
Ref Pr	Low Pr	High Pr	
40%	30%	50%	1. Continued acceptance of royal family, and insulation from regional instability, no major policy-driven outages, Aramco maintains high operating standards
20%	25%	15%	2. Major policy-driven temporary reduction
15%	15%	15%	3. Significant but temporary infrastructure problem from attack or technical failure and/or isolated conflict that results in attacks on infrastructure without profound internal implications
15%	15%	15%	4. Regional conflict with neighbors combined with internal political crisis, failed infrastructure and/or sabotage which is difficult to fix
10%	15%	5%	5. Full domestic instability

Table C.4. Probabilities for Other Persian Gulf Internal Events

3 Other Persian Gulf Internal Factors

Oil Price Scenarios			
Ref Pr	Low Pr	High Pr	
35%	25%	45%	1. Stable regional oil output, Iraq attracts sufficient investment, Iranian agreement holds, and no major policy-driven outages
10%	10%	5%	2. Major policy-driven temporary reduction
20%	25%	20%	3. Significant but temporary infrastructure problem from attack or technical failure and/or isolated conflict that results in attacks on infrastructure without profound internal implications
20%	25%	15%	4. One or more significant regional actors becomes failed states that disrupt production and exports
15%	15%	15%	5. Regional conflict with neighbors combined with internal political crisis, failed infrastructure and/or sabotage which is difficult to fix, constraining access to Strait of Hormuz

Table C.5. Probabilities for Africa Internal Events

16 Africa Internal Factors

Oil Price Scenarios			
Ref Pr	Low Pr	High Pr	
5%	1%	15%	1. Relative regional stability, limited small attacks/piracy/technical failures; countries/companies remain solvent; moderate labor unrest and operational accidents
70%	80%	70%	2. In 1-2 countries, internal conflict and/or aggressive borderless entities targeting oil infrastructure (e.g., ISIS, MEND)
15%	4%	10%	3. Interstate conflict between 2 countries with significant on shore production resulting in damaging assets (e.g., Libya, Egypt); fiscal failure of one or more countries and/or companies
10%	15%	5%	4. Widespread unrest in large region (Arab Spring 2); widespread attacks against oil infrastructure; toppling of governments; failed state (s)

Table C.6. Probabilities for Latin America Internal Events

Oil Price Scenarios			19 Latin America Internal Factors
Ref Pr	Low Pr	High Pr	
40%	1%	54%	1. Relative regional stability; limited small attacks/technical failures; countries/companies remain solvent
50%	64%	40%	2. Some sanctions imposed; disruptive labor unrest and substantial technical/operational accidents; fiscal challenges for national oil companies
5%	25%	5%	3. Interstate conflict between 2 countries with significant on shore production resulting in damaging assets (e.g., Venezuela, Columbia) and/or fiscal failure of one or more countries and/or companies
5%	10%	1%	4. Widespread unrest leading to region-wide Pan-American social upheaval; widespread attacks against oil infrastructure

Table C.7. Probabilities for Russia and Caspian States Internal Events

Oil Price Scenarios			13 Russia & Caspian States Internal Factors
Ref Pr	Low Pr	High Pr	
30%	15%	50%	1. Status quo; small isolated attacks
45%	50%	30%	2. 2-3 of the following: voluntary production cuts; moderate transit disruptions; temporary disruptions from economic/political strife; sabotage /terminal attack
20%	30%	15%	3. 1-2 of the following: Large cut-offs resulting from interstate conflict; collapse of a major Russian producer; succession crisis in Russia
5%	5%	5%	4. Major war or disruptions to transit; assumes ban on Russian oil would occur

Table C.8. Probabilities for Saudi Shortfall Amount

5 Saudi Shortfall

Middle East Conflict: Minimal Conflict

Shortfall Amount	Saudi Internal Factors	Stable	Major policy-driven reduction	Tech Failure or Isolated Conflict	Reg Conflict with Internal Crisis	Full social rev; curtail exports
	None (<10%)	100%	0%	80%	50%	10%
	Small (10-30%)	0%	95%	20%	30%	50%
	Medium (30-80%)	0%	5%	0%	15%	30%
	All (>80%)	0%	0%	0%	5%	10%

happened in 1993

Middle East Conflict: Growing Domestic Unrest

Shortfall Amount	Saudi Internal Factors	Stable	Major policy-driven reduction	Tech Failure or Isolated Conflict	Reg Conflict with Internal Crisis	Full social rev; curtail exports
	None (<10%)	100%	0%	75%	40%	10%
	Small (10-30%)	0%	95%	25%	40%	50%
	Medium (30-80%)	0%	5%	0%	15%	30%
	All (>80%)	0%	0%	0%	5%	10%

Middle East Conflict: Growing Political Unrest (Like Current)

Shortfall Amount	Saudi Internal Factors	Stable	Major policy-driven reduction	Tech Failure or Isolated Conflict	Reg Conflict with Internal Crisis	Full social rev; curtail exports
	None (<10%)	95%	0%	70%	35%	10%
	Small (10-30%)	5%	95%	30%	45%	50%
	Medium (30-80%)	0%	5%	0%	15%	30%
	All (>80%)	0%	0%	0%	5%	10%

Middle East Conflict: Limited Interstate Unrest

Shortfall Amount	Saudi Internal Factors	Stable	Major policy-driven reduction	Tech Failure or Isolated Conflict	Reg Conflict with Internal Crisis	Full social rev; curtail exports
	None (<10%)	80%	0%	60%	30%	10%
	Small (10-30%)	20%	95%	35%	45%	40%
	Medium (30-80%)	0%	5%	5%	20%	40%
	All (>80%)	0%	0%	0%	5%	10%

Middle East Conflict: Wider-spread Interstate Conflict

Shortfall Amount	Saudi Internal Factors	Stable	Major policy-driven reduction	Tech Failure or Isolated Conflict	Reg Conflict with Internal Crisis	Full social rev; curtail exports
	None (<10%)	60%	0%	50%	25%	5%
	Small (10-30%)	30%	95%	35%	40%	35%
	Medium (30-80%)	10%	5%	10%	25%	45%
	All (>80%)	0%	0%	5%	10%	15%

Table C.9. Probabilities for Other Persian Gulf Shortfall Amount

8 Other Persian Gulf Shortfall

Middle East Conflict: Minimal Conflict

	OPG Internal Factors	Stable	Major policy-driven reduction	Tech Failure or Isolated Conflict	Failed States	Regional Conflict with Internal Crisis
Shortfall Amount	None (<10%)	100%	0%	70%	10%	15%
	Small (10-30%)	0%	100%	30%	60%	50%
	Medium (30-80%)	0%	0%	0%	30%	35%
	All (>80%)	0%	0%	0%	0%	0%

Middle East Conflict: Growing Domestic Unrest

	OPG Internal Factors	Stable	Major policy-driven reduction	Tech Failure or Isolated Conflict	Failed States	Regional Conflict with Internal Crisis
Shortfall Amount	None (<10%)	80%	0%	55%	5%	10%
	Small (10-30%)	20%	100%	35%	65%	55%
	Medium (30-80%)	0%	0%	10%	30%	35%
	All (>80%)	0%	0%	0%	0%	0%

Middle East Conflict: Growing Political Unrest (Like Current)

	OPG Internal Factors	Stable	Major policy-driven reduction	Tech Failure or Isolated Conflict	Failed States	Regional Conflict with Internal Crisis
Shortfall Amount	None (<10%)	75%	0%	50%	5%	5%
	Small (10-30%)	25%	100%	40%	65%	55%
	Medium (30-80%)	0%	0%	10%	30%	40%
	All (>80%)	0%	0%	0%	0%	0%

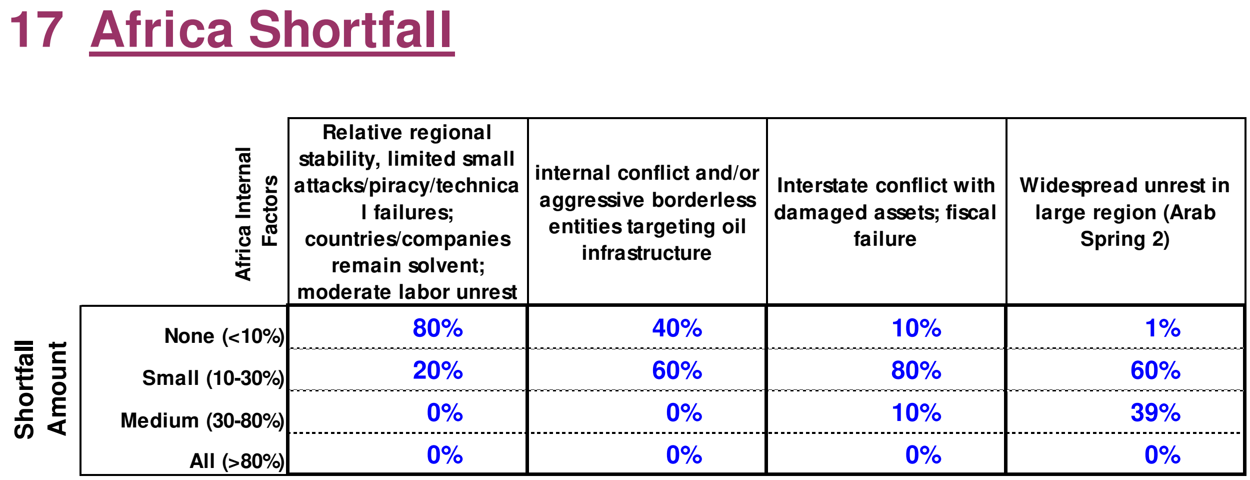
Middle East Conflict: Limited Interstate Unrest

	OPG Internal Factors	Stable	Major policy-driven reduction	Tech Failure or Isolated Conflict	Failed States	Regional Conflict with Internal Crisis
Shortfall Amount	None (<10%)	70%	0%	45%	0%	0%
	Small (10-30%)	30%	100%	45%	70%	60%
	Medium (30-80%)	0%	0%	10%	30%	40%
	All (>80%)	0%	0%	0%	0%	0%

Middle East Conflict: Wider-spread Interstate Conflict

	OPG Internal Factors	Stable	Major policy-driven reduction	Tech Failure or Isolated Conflict	Failed States	Regional Conflict with Internal Crisis
Shortfall Amount	None (<10%)	60%	0%	40%	0%	0%
	Small (10-30%)	35%	100%	45%	60%	60%
	Medium (30-80%)	5%	0%	15%	40%	35%
	All (>80%)	0%	0%	0%	0%	5%

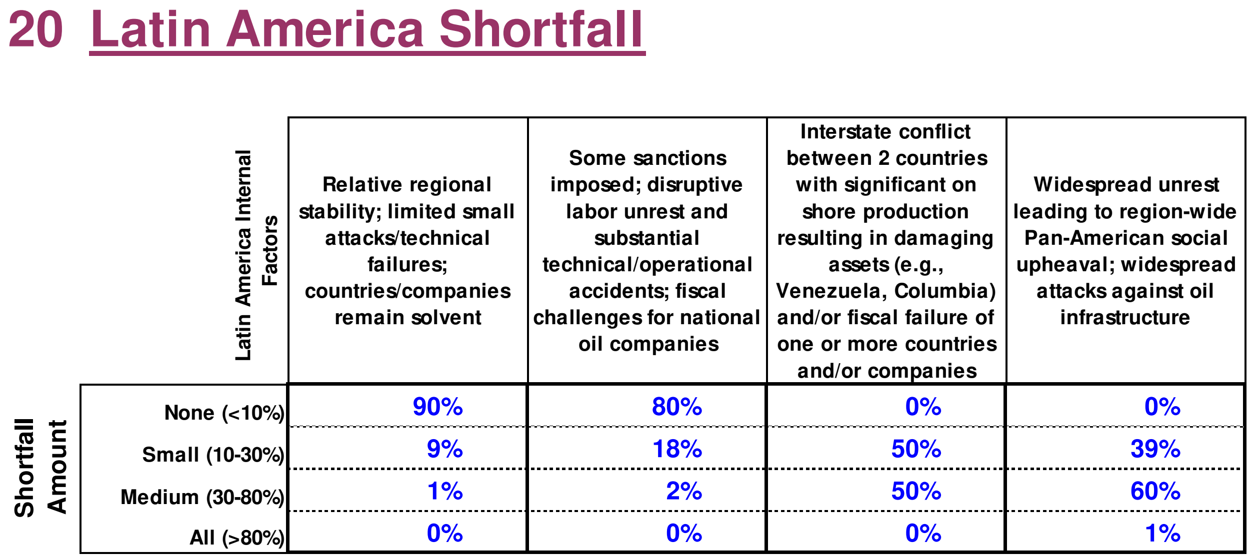
Table C.10. Probabilities for Africa Shortfall Amount



17 Africa Shortfall

Shortfall Amount	Africa Internal Factors	Relative regional stability, limited small attacks/piracy/technical failures; countries/companies remain solvent; moderate labor unrest	internal conflict and/or aggressive borderless entities targeting oil infrastructure	Interstate conflict with damaged assets; fiscal failure	Widespread unrest in large region (Arab Spring 2)
	None (<10%)	80%	40%	10%	1%
	Small (10-30%)	20%	60%	80%	60%
	Medium (30-80%)	0%	0%	10%	39%
	All (>80%)	0%	0%	0%	0%

Table C.11. Probabilities for Latin America Shortfall Amount



20 Latin America Shortfall

Shortfall Amount	Latin America Internal Factors	Relative regional stability; limited small attacks/technical failures; countries/companies remain solvent	Some sanctions imposed; disruptive labor unrest and substantial technical/operational accidents; fiscal challenges for national oil companies	Interstate conflict between 2 countries with significant on shore production resulting in damaging assets (e.g., Venezuela, Columbia) and/or fiscal failure of one or more countries and/or companies	Widespread unrest leading to region-wide Pan-American social upheaval; widespread attacks against oil infrastructure
	None (<10%)	90%	80%	0%	0%
	Small (10-30%)	9%	18%	50%	39%
	Medium (30-80%)	1%	2%	50%	60%
	All (>80%)	0%	0%	0%	1%

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

14 Russia & Caspian States Shortfall

Russia-West Conflict: None

	Russia & Caspian States Internal Factors	Status quo; small isolated attacks	voluntary production cuts; moderate transit disruptions; temp disruptions from economic/political strife; sabotage /terminal attack	Large cut-offs resulting from interstate conflict; collapse of a major Russian producer; succession crisis in Russia	Major war or disruptions to transit; assumes ban on Russian oil would occur
Amount	None (<10%)	98%	75%	18%	0%
	Small (10-30%)	2%	25%	50%	65%
	Medium (30-80%)	0%	0%	30%	32%
	All (>80%)	0%	0%	2%	3%

Russia-West Conflict: Only hybrid* conflict

	Russia & Caspian States Internal Factors	Status quo; small isolated attacks	voluntary production cuts; moderate transit disruptions; temp disruptions from economic/political strife; sabotage /terminal attack	Large cut-offs resulting from interstate conflict; collapse of a major Russian producer; succession crisis in Russia	Major war or disruptions to transit; assumes ban on Russian oil would occur
Amount	None (<10%)	98%	70%	18%	0%
	Small (10-30%)	2%	30%	50%	65%
	Medium (30-80%)	0%	0%	30%	32%
	All (>80%)	0%	0%	2%	3%

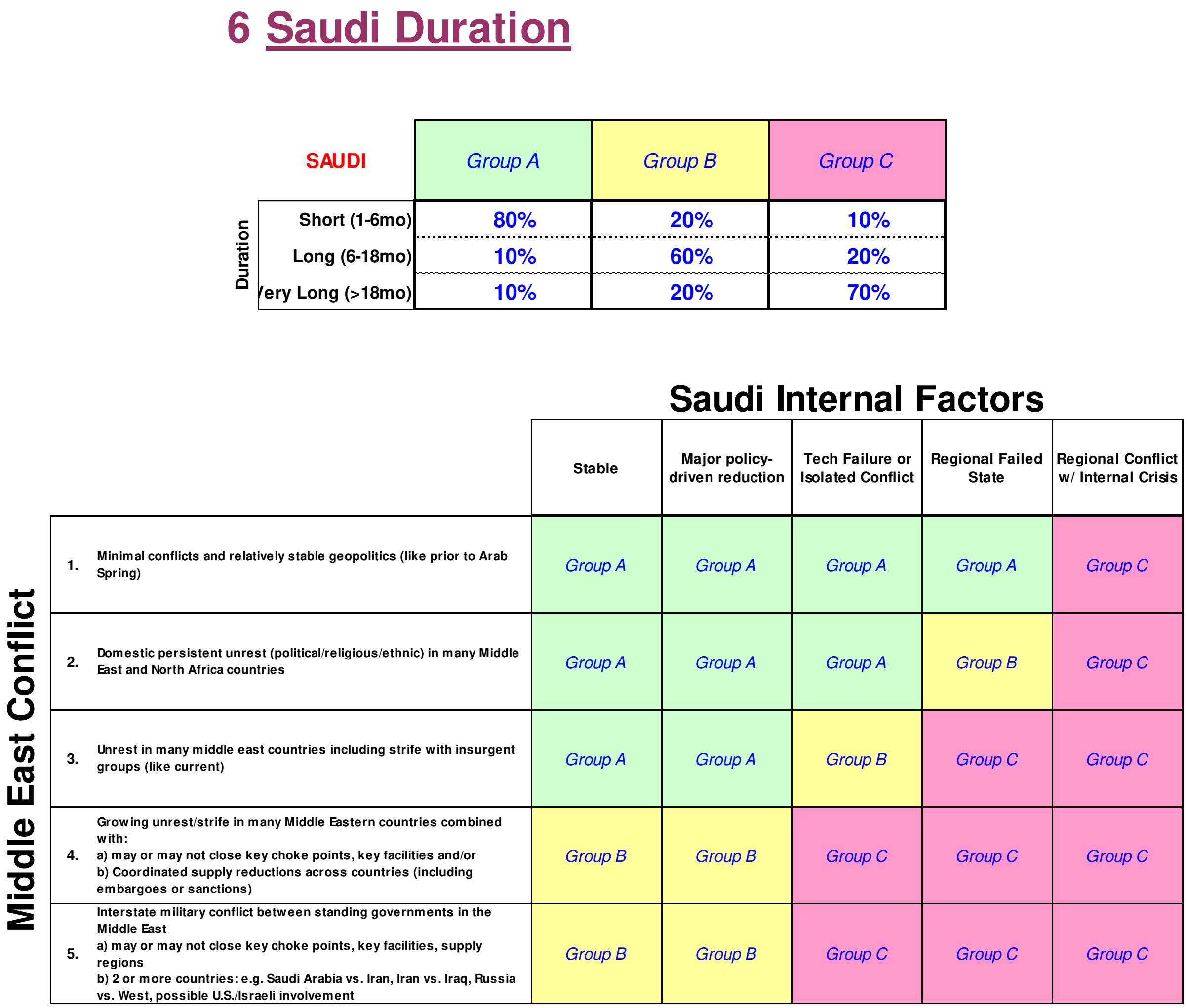
Russia-West Conflict: Conflict Russia/Western Non-Nato nation

	Russia & Caspian States Internal Factors	Status quo; small isolated attacks	voluntary production cuts; moderate transit disruptions; temp disruptions from economic/political strife; sabotage /terminal attack	Large cut-offs resulting from interstate conflict; collapse of a major Russian producer; succession crisis in Russia	slightly higher change to have a negative production impact than scenario above
Amount	None (<10%)	80%	60%	10%	0%
	Small (10-30%)	20%	40%	55%	60%
	Medium (30-80%)	0%	0%	33%	37%
	All (>80%)	0%	0%	2%	3%

Russia-West Conflict: Conflict Russia/Western NATO nation

	Russia & Caspian States Internal Factors	Status quo; small isolated attacks	voluntary production cuts; moderate transit disruptions; temp disruptions from economic/political strife; sabotage /terminal attack	Large cut-offs resulting from interstate conflict; collapse of a major Russian producer; succession crisis in Russia	Major war or disruptions to transit; assumes ban on Russian oil would occur
Amount	None (<10%)	75%	40%	0%	0%
	Small (10-30%)	25%	55%	48%	25%
	Medium (30-80%)	0%	5%	50%	70%
	All (>80%)	0%	0%	2%	5%

Table C.13. Probabilities for Saudi Duration



6 Saudi Duration

	SAUDI	Group A	Group B	Group C
Duration	Short (1-6mo)	80%	20%	10%
	Long (6-18mo)	10%	60%	20%
	Very Long (>18mo)	10%	20%	70%

Saudi Internal Factors

			Stable	Major policy-driven reduction	Tech Failure or Isolated Conflict	Regional Failed State	Regional Conflict w/ Internal Crisis
Middle East Conflict	1.	Minimal conflicts and relatively stable geopolitics (like prior to Arab Spring)	Group A	Group A	Group A	Group A	Group C
	2.	Domestic persistent unrest (political/religious/ethnic) in many Middle East and North Africa countries	Group A	Group A	Group A	Group B	Group C
	3.	Unrest in many middle east countries including strife with insurgent groups (like current)	Group A	Group A	Group B	Group C	Group C
	4.	Growing unrest/strife in many Middle Eastern countries combined with: a) may or may not close key choke points, key facilities and/or b) Coordinated supply reductions across countries (including embargoes or sanctions)	Group B	Group B	Group C	Group C	Group C
	5.	Interstate military conflict between standing governments in the Middle East a) may or may not close key choke points, key facilities, supply regions b) 2 or more countries: e.g. Saudi Arabia vs. Iran, Iran vs. Iraq, Russia vs. West, possible U.S./Israeli involvement	Group B	Group B	Group C	Group C	Group C

Table C.14. Probabilities for Other Persian Gulf Duration

9 Other Persian Gulf Duration

	OPG	Group A	Group B	Group C
Duration	Short (1-6mo)	70%	15%	10%
	Long (6-18mo)	15%	60%	15%
	Very Long (>18mo)	15%	25%	75%

Other Persian Gulf Internal Factors

			Stable	Major policy-driven reduction	Tech Failure or Isolated Conflict	Regional Failed State	Regional Conflict w/ Internal Crisis
Middle East Conflict	1.	Minimal conflicts and relatively stable geopolitics (like prior to Arab Spring)	Group A	Group A	Group A	Group B	Group C
	2.	Domestic persistent unrest (political/religious/ethnic) in many Middle East and North Africa countries	Group A	Group A	Group A	Group B	Group C
	3.	Unrest in many middle east countries including strife with insurgent groups (like current)	Group A	Group A	Group B	Group C	Group C
	4.	Growing unrest/strife in many Middle Eastern countries combined with: a) may or may not close key choke points, key facilities and/or b) Coordinated supply reductions across countries (including embargoes or sanctions)	Group B	Group B	Group C	Group C	Group C
	5.	Interstate military conflict between standing governments in the Middle East a) may or may not close key choke points, key facilities, supply regions b) 2 or more countries: e.g. Saudi Arabia vs. Iran, Iran vs. Iraq, Russia vs. West, possible U.S./Israeli involvement	Group B	Group B	Group C	Group C	Group C

Table C.15. Probabilities for Africa Duration

18 Africa Duration

	Africa Internal Factors	Relative regional stability, limited small attacks/piracy/technical failures; countries/companies remain solvent; moderate labor unrest	internal conflict and/or aggressive borderless entities targeting oil infrastructure	Interstate conflict with damaged assets; fiscal failure	Widespread unrest in large region (Arab Spring 2); toppling of governements; failed state (s)
Duration	Short (1-6mo)	80%	50%	20%	10%
	Long (6-18mo)	10%	30%	30%	20%
	Very Long (>18mo)	10%	20%	50%	70%

Table C.16. Probabilities for Latin America Duration

21 Latin America Duration

	Latin America Internal Factors	Relative regional stability; limited small attacks/technical failures; countries/companies remain solvent	Some sanctions imposed; disruptive labor unrest and substantial technical/operational accidents; fiscal challenges for national oil companies	Interstate conflict between 2 countries with significant on shore production resulting in damaging assets (e.g., Venezuela, Columbia) and/or fiscal failure of one or more countries and/or companies	Widespread unrest leading to region-wide Pan-American social upheaval; widespread attacks against oil infrastructure
Duration	Short (1-6mo)	80%	50%	30%	10%
	Long (6-18mo)	10%	30%	30%	30%
	Very Long (>18mo)	10%	20%	40%	60%

Table C.17. Probabilities for Russia and Caspian States Duration

15 Russia & Caspian States Duration

Russia-West Conflict: None

	Russia & Caspian States Internal Factors	Status quo; small isolated attacks	voluntary production cuts; moderate transit disruptions; temp disruptions from economic/political strife; sabotage /terminal attack	Large cut-offs resulting from interstate conflict; collapse of a major Russian producer; succession crisis in Russia	Major war or disruptions to transit; assumes ban on Russian oil would occur
Duration	Short (1-6mo)	98%	95%	90%	85%
	Long (6-18mo)	2%	4%	7%	10%
	Very Long (>18mo)	0%	1%	3%	5%

Russia-West Conflict: Only Hybrid Conflict

	Russia & Caspian States Internal Factors	Status quo; small isolated attacks	voluntary production cuts; moderate transit disruptions; temp disruptions from economic/political strife; sabotage /terminal attack	Large cut-offs resulting from interstate conflict; collapse of a major Russian producer; succession crisis in Russia	Major war or disruptions to transit; assumes ban on Russian oil would occur
Duration	Short (1-6mo)	98%	97%	80%	70%
	Long (6-18mo)	2%	2%	15%	20%
	Very Long (>18mo)	0%	1%	5%	10%

Russia-West Conflict: Conflict Russia/Non-Nato

	Russia & Caspian States Internal Factors	Status quo; small isolated attacks	voluntary production cuts; moderate transit disruptions; temp disruptions from economic/political strife; sabotage /terminal attack	Large cut-offs resulting from interstate conflict; collapse of a major Russian producer; succession crisis in Russia	Major war or disruptions to transit; assumes ban on Russian oil would occur
Duration	Short (1-6mo)	98%	80%	70%	55%
	Long (6-18mo)	2%	19%	25%	30%
	Very Long (>18mo)	0%	1%	5%	15%

Russia-West Conflict: Conflict Russia/NATO

	Russia & Caspian States Internal Factors	Status quo; small isolated attacks	voluntary production cuts; moderate transit disruptions; temp disruptions from economic/political strife; sabotage /terminal attack	Large cut-offs resulting from interstate conflict; collapse of a major Russian producer; succession crisis in Russia	Major war or disruptions to transit; assumes ban on Russian oil would occur
Duration	Short (1-6mo)	98%	70%	20%	1%
	Long (6-18mo)	2%	29%	60%	2%
	Very Long (>18mo)	0%	1%	20%	97%

Table C.18. Probabilities for Middle East Choke Point

4 Middle East Choke Points

	Choke		
0	4MMBD	8 MMBD	
100%	0%	0%	1. Minimal conflicts and relatively stable geopolitics (like prior to Arab Spring)
99%	1%	0%	2. Domestic persistent unrest (political/religious/ethnic) in many Middle East and North Africa countries
95%	5%	0%	3. Unrest in many middle east countries including strife with insurgent groups (like current)
85%	14%	1%	4. Growing unrest/strife in many Middle Eastern countries combined with: a) may or may not close key choke points, key facilities and/or b) Coordinated supply reductions across countries (including embargoes or sanctions)
20%	60%	20%	5. Interstate military conflict between standing governments in the Middle East a) may or may not close key choke points, key facilities, supply regions b) 2 or more countries: e.g. Saudi Arabia vs. Iran, Iran vs. Iraq, Russia vs. West, possible U.S./Israeli involvement

Table C.19. Probabilities for Saudi Excess Capacity

7 Saudi Excess Capacity

None	25%
0.5 MMBD	5%
1 MMBD	25%
1.5 MMBD	25%
2 MMBD	20%

Table C.20. Probabilities for Other Persian Gulf Excess Capacity

10 Other Persian Gulf Excess Capacity

None	85%
0.5 MMBD	15%

Table C.21. Probabilities for Oil Production Scenarios

11 World Oil Production 2020

30%	High Price Case	(94.8 MMBD; OPEC Share=35%)
40%	Reference Price Case	(97.6 MMBD; OPEC Share=40%)
30%	Low Price Case	(99.4 MMBD; OPEC Share=44%)

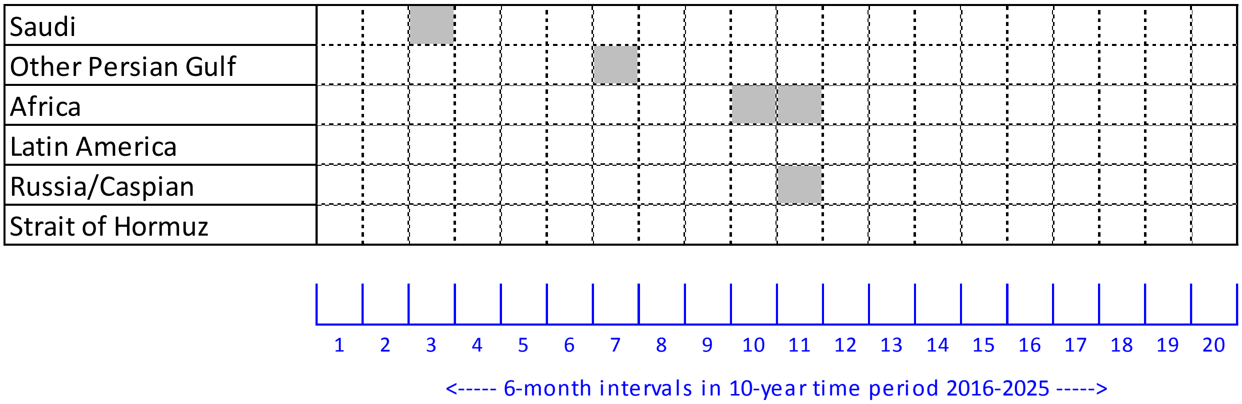
APPENDIX D: DISRUPTION SIZE AND OVERLAP

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. For purposes of simulating the possible scenarios of disruption timing, the 10-year horizon is divided into twenty 6-month periods. For each region that has a disruption, the timing of the initial period of the disruption is treated as uncertain, with a uniform probability distribution over the twenty periods. In addition to the five regions that have been discussed, we have added a 6th region: The Strait of Hormuz, which is treated as a pseudo-region with its own initial period (the first period the disruption occurs) and duration of disruption (how long the disruption lasts).

The duration of each disruption can be either Short, Long or Very Long. A Short duration disruption is assumed to occur in one period (6 months), a Long disruption in two periods (12 months), and a Very Long disruption in 4 periods (24 months).

In periods in which more than one disruption occurs, shortfalls are added to calculate the total amount of disruption for that period. Figure D.1 shows a possible scenario of the timing of disruptions in four regions. The total disruption in period 11 would be the sum of the Africa shortfall and the Russia/Caspian shortfall.

Figure D.1. Timeline for Disruptions



To determine the net disruption, the total disruption in each period is reduced by the amount of the excess capacity (Saudi plus Other Persian Gulf) for the scenario in question.

The maximum Short (6-month) net disruption is the maximum net disruption over the twenty periods.

The maximum Long (12-month) net disruption is the maximum of the minimum[6] disruption for each of the 19 two-period subintervals in the 10-year horizon. The subintervals consist of periods 1&2, 2&3, ..., 19&20. In the example shown in Figure D.1, the only two-period subinterval with disruption in both of its periods is 10&11. Thus, the maximum Long net disruption would be the level of the Africa shortfall, less the excess capacity, or zero if the excess capacity is more than the Africa shortfall.

Similarly, the maximum Very Long (24-month) net disruption is the maximum of the minimum disruption for each of the 17 four-period subintervals in the 10-year horizon. The subintervals consist of periods 1-4, 2-5, ..., 17-20. In the example above, there is no four-period subinterval with nonzero disruption in all of its periods, hence the maximum Very Long net disruption would be zero.

In the 2005 study, we approximated the overlap by estimating a probability of overlap for short, long, and very long disruptions. In the current study, this approximation is replaced by a bottoms-up perspective wherein we consider disruptions period by period.

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[6] For each 12-month period, we must take the minimum disruption. For example, if the first 6-month period had 2 MMBD disrupted, and the 2nd 6-month period had 3 MMBD disrupted, a Long disruption lasting 12 months should have a size of 2 MMBD, the minimum disruption over the 12-month period. In this example, the size of 3 MMBD is a Short duration disruption, not a long duration disruption

APPENDIX E: HISTORICAL DISRUPTIONS

Table E.1. Historical Disruptions

				Disruption	Gross
	Oil Supply Disruption Event		Start Date	Length	Shortfall
#	Description	Cause of Disruption	Months	Months	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

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