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# Improving Risk Management in Oil and Gas Mega-Projects

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***Abstract:***
*Oil and gas projects continue to grow in size and complexity, leading to additional project risk. Exploration and production companies can inadvertently accept more risk than expected in large scale projects, often because of underestimating the effects of rare but significant events. This paper outlines several areas where companies can improve internal risk management for large scale projects. This paper will be of interest to project managers and risk management researchers concerned with oil and gas mega-projects.*

***Keywords:*** *Oil and gas, mega-project, risk management, economic analysis*

## 1. Introduction

This best practices guide for risk management plans is intended to inform project teams that create individualized project risk management plans for large-scale construction projects within the oil and gas industry. These projects, often called"mega- projects," are characterized by substantial non-routine work elements and capital budgets exceeding $1 billion. The purpose of risk management strategies for the project is to reduce losses and provide protection against extreme events that could adversely affect the project (Kunreuther, 2002).

The development of mega-projects relies heavily on project management expertise. Within the scope of project management, the project team is concerned with risks that could affect the project's three basic objectives:

- Schedule. Will the project be completed on time?
- Cost. Will the project be completed within budget?
- Scope. Will the system satisfy the goal(s) of the project? (Galway, 2004).

There are myriad risks that could affect each objective. For example, given the high capital outlay, the sponsor companies are sensitive to schedule because project delays extend the time before the project begins to generate income. Most mega-projects receive funding from third-party sources and it may not be possible to secure additional funds beyond the project budget - meaning that cost overruns could scuttle the project. The scope of the project is also important because the project cannot be operated safely for decades if it is not constructed to the appropriate specifications.

The purpose of this guide is to help project teams use best practices that have been identified in research literature in order to make better decisions about the risks facing their project.

### *1.1. Defining Risk Management*

Risk management is the process of identifying, assessing, responding to, monitoring, and reporting risks. A Risk Management Plan provides an approach for overall project risks. The plan outlines how risks will be identified, analyzed, and managed. It delineates how risk management activities will be performed, recorded, and monitored throughout the lifecycle of the project.

The project manager has responsibility for creating the Risk Management Plan during the Planning Phase of a project and is responsible for the monitoring and updating of the plan throughout the project. The plan is a working document intended to inform decisions the project team, project sponsor and project stakeholders.

### *1.2. Risk Scenarios*

Risk has many different definitions. This plan defines risk as an uncertain event, which has a negative impact on the project (Galway, 2004). Put more simply,"Risk is probability and consequence" (Kaplan and Garrick, 1981) such that risk can be measured by:

- The probability (or likelihood) of failing to achieve a project objective
- The consequences (or impact) of failing to achieve that objective (Walden et al., 2015)

Within a project each risk can ladder up to affecting the project's ability to achieve its schedule, cost, and scope. Risks can then be defined by a scenario (S), probability (φ), and consequence (X) such that $R = \{(S_i, p(\varphi)_i, p(X)_i)\}_C$ (Kaplan, 1997). Scenarios should be assessed using vectors for (1) the magnitude (or severity) of the adverse consequence(s) that can potentially result from the given activity or action, and (2) by the likelihood of occurrence of the given adverse consequence(s) (Kaplan and Garrick, 1981). When considering scenarios, probability and consequence should be kept as vector pairs, rather than combined into a single unit. Combining probability and consequence assumes that the project is risk neutral, which is seldom the case. A catalog of scenarios, can be constructed using a basic "Condition-if-then" structure (Garvey, 2008).

| Protesters Prevent Access to the Facility | Construction Stops | Project Is Delayed |
|---|---|---|
| New regulations change project requirements | Construction stops | Project is delayed |
| Weather delays supply shipment | Alternative supply purchased | Project costs increase |

*Table 1: Sample Scenario Catalog about Here*

The project team should consider scenarios relevant to the specific project. There are scenario libraries commercially available which the project team can use to augment the bespoke scenario catalog (Hubbard, 2009).

## 2. Risk Management Procedure

*2.1. Recursive Process*

The project manager working with the project team and project sponsors should ensure that project risks are actively identified, analyzed, and managed throughout the life of the project. Risks should be identified as early as possible in the project so as to minimize their impact. Steps for identifying, assessing and mitigating risks are described in the following sections. The risk management system should be reassessed as the project reaches various milestones and the project's risk profile changes.

Project management best practices use the cost and influence curve to demonstrate the affects of late stage changes in project scope (Snyder, 2014). This framework applies equally to risk identification and management. This model shows the clear relationship between early risk identification and reduced cost, relative to later risk mitigation.

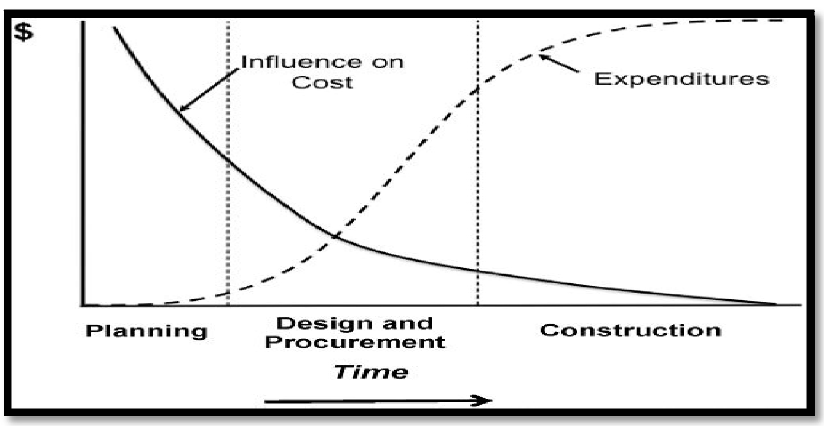


*Figure 1: Project Management Cost-Influence Curve*

The options for risk management change during the different phases of a project. Early risk identification is the best practice for mitigating project risks (Center, 2010).

*2.2. Risk Identification*

The project should seek to identify and quantify as many risks as possible for all aspects of the project. The goal of risk identification is to answer three basic questions (Stamatelatos, 2000):

- What could go wrong? What are the initiating events that could lead to negative consequences?
- How severe are the potential risks? To what extent will the risk cause delays to schedule, increase project costs or degrade project quality?
- How likely are these negative consequences to occur?

The project risk identification process is comprised on risks identified for the overall project and for components within the project such as Health, Safety and Environment, Technical, Legal, Financial and Political risk. Each subteam of the project should contribute to the overall risk assessment because non-technical risks have as much potential to negatively effect the project's objectives as technical risks. Data show that engineers tend to focus on technical risk more than others (Smith et al., 2009). Knowing this, the project should be extra vigilant to include non-technical risks in the risk management plan. For example, fluctuations in foreign exchange rates could pose greater risk to the projects budget than cost overruns on specific components to the project.

In addition to identifying risks within subteams, the project risk plan should consider the complex interdependence of those sub-risks because a single event could have consequences for multiple subteams. For example, a fire caused by faulty equipment could pose technical, financial, and Health, Safety, and Environmental risks. Considered this way, the project risk management system is a system of systems.

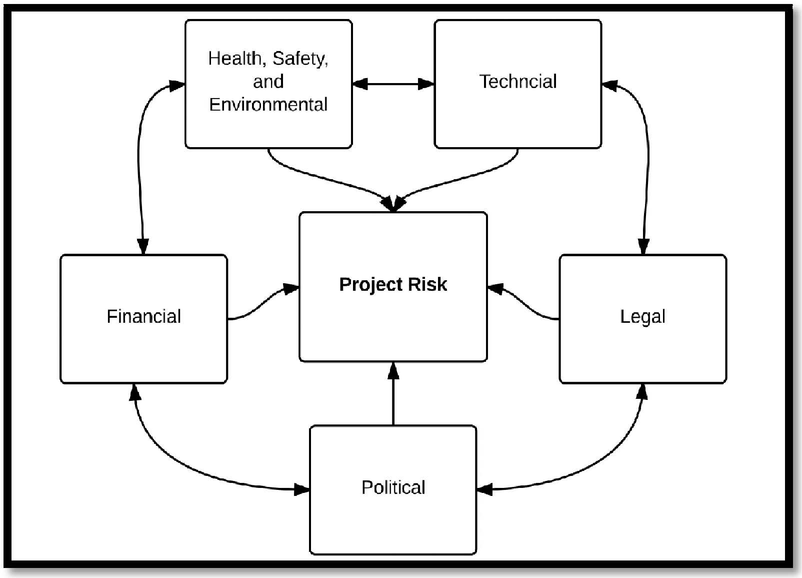


*Figure 2: System of Systems*

The risks within the constituent parts of a project combine to form the project risk catalog. The constituent risks also may also have independence between subteams.

The risk identification process should be iterative because risk and their associated probabilities change during the lifecycle of a project. Importantly, risk mitigation options change over the lifecycle of the project such that some options become unfeasible once the project is beyond a certain phase/gate.

The objective of risk identification is to catalog all possible risks but even an extensive risk log will not be exhaustive. The project team should retain some capital and should plan some buffer time to serve as contingency against unknown, and unknowable, risks.

## 3. Risk Analysis

Once the project risks have been identified, the risks need to be analyzed. Risk analysis serves as both a guidance document for prioritizing risk and as a tool for "structured thinking and alignment" about the risks a project may encounter (Galway, 2004).

All risks identified should be assessed to identify the range of possible project outcomes. These risks are prioritized to determine which risks are the top risks to pursue and respond to and which risks can be ignored. Risk analysis includes quantitative and qualitative components (Galway, 2004).

### *3.1. Probabilistic Risk Assessment*

There are some risks which could have catastrophic consequences for the project, leading to delays longer than 1 year. The severity of these risks merits the expense of conducting a quantitatively based probability risk assessment (PRA) (Lund, 2008). The PRA provides a structured, iterative toolset for the project team.

When possible, the data used for modeling risk should be derived from operational data. The data should be updated after events to include actual outcomes, such as costs incurred. There operational data is not available, the analysis should include estimates from a number of sources, including expert opinion (Stamatelatos, 2000). Experts should be given feedback about the accuracy of their predictions in order to help calibrate future estimates (Hubbard, 2009).

The project may not have quantitative data on all risks. In those cases, a small amount of data can reduce a lot of uncertainty. What data can be used can provide ranges which are more scientific than estimates from non-quantitative sources, such as expert opinion

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*3.2. Quantitative Risk Analysis*

Quantitative data should drive the risk analysis. There are several ways to find quantitative data about project risk. Some sources of data include:

- Historical performance of successes and failures of similar projects with the industry
- Historical performance of successes and failures of similar projects outside the industry
- Industry databases of component failure data such as the Reliability Information Analysis Center, which maintains databases for electronic and no electronic parts reliability (Stamatelatos et al., 2011).
- Curated risk scenario libraries such as Stochastic Information Packets (SIPs) (Hubbard, 2009).
- Commercial databases about common risks such as weather, foreign exchange and political stability (Hubbard, 2009).

If those sources are not available, then the project team can consult surrogate sources (Stamatelatos et al., 2011). Some sources of surrogate data include:

- Political betting markets to assess political risk such as Intrade
- Law and economics scholarship to assess legal risk
- Rating agency reports to assess financial risk
- Industry reports such as the 'War risks and terrorism' research report by the Insurance Institute of London to assess

Low probability, high consequence risks another source for data about project risks are near-miss events. These are events which but for luck would have had severe negative consequences on the project's objectives. Including near-miss events allows the project team to use real data on the scenario that occurred, rather than simulated models for risk. Incorporating near-miss data into risk assessments has been successfully used to reduce Safely, Health and Environmental risk. In safety, near-miss data is considered a leading indicator instead of a lagging indicator because it can be used to predict future safety risks. The same approach can apply to other project risks.

*3.3. Qualitative Risk Analysis*

There are some risks which need input from subject matter experts. However, research demonstrates that qualitative assessments are susceptible to heuristic biases which can lead to severe and systematic errors (Tversky and Kahneman, 1974). It is possible for experts to improve the accuracy of their predictions through calibration. Critical to calibration is feedback to the expert about the outcome of the event. Expert opinion is often used when there is not sufficient data. Unfortunately, experts have the most difficulty interpreting low probability events and this can lead to systemic errors in the analysis (Kunreuther et al., 2001). Decision science scholarship has identified several areas where experts are prone to systematic errors. Tversky and Kahne- man 1974 outlined three specific heuristics of concern when relying on experts to assess project risk:

Representativeness: Individuals assess events based on how representative they deem the outcome to be. Adjustment and anchoring: Individuals are susceptible to arbitrary anchor points from which they adjust their predictions up or down For mega-projects, there are three other heuristics which can introduce risks in the risk assessment process. Availability bias when considering uncommon events people tend to judge the probability based on how well they can recall the last instance of that event. People will underestimate how often some events happen because they are hard to recall, and over estimate other events because that event may have been top of mind. For example, people increase the probability of auto accidents or terrorist events when those events have been recently covered in the news. Risk managers can use paired comparison quantitative methods to see if some estimates are systematically biased because of availability. Framing People react differently depending on how a problem is presented (Tversky and Kahneman, 1981). In rational economic theory, decision makers should be indifferent to how decisions are presented but the framing does influence the decision. There are two attendant risks within framing:

- Experts will provide different answers depending on how a question is asked
- Decision makers can focus on the wrong risks based on how those risks are presented

To counteract this heuristic, the project team should include diverse perspectives in the risk analysis and management steps. Outside reviews, or cold eyes or peer reviews, are often able to identify areas where framing has led to suboptimal outcomes.

Overconfidence

Experts have a strong tendency to be overconfidence in their predictions. This overconfidence can skew a model leading to unreliable results and the systematic underestimation of risk (Tversky and Kahneman, 1981). Overconfidence can be overcome through calibration and through sophisticated quantitative tools such as the Classical Method. Under the classical methods, risk managers can that measure how well experts do at estimating known events (almanac knowledge) and use that to determine how accurate an experts opinion might be.

3.3.1. Eliciting Data from Experts

Applying quantitative tools to qualitative data can help overcome heuristics. There are several techniques for assessing risk probabilities and frequencies from experts.

One method for eliciting information from experts is to survey the experts and test their responses using the classical method. In this method the experts provide ranges for risks as well as ranges for unrelated, almanac knowledge. The unrelated data are used to help calibrate an expert's responses. Over time, experts can learn to calibrate their responses and improve the accuracy of their predictions. That calibration requires feedback to the experts about the accuracy of their predictions.

The Delphi method is another approach to calibrating experts' predictions. In this method, experts complete a series of surveys where the results of the previous survey are included in the subsequent survey. While time consuming, this round-robin method can lead to experts coming to a consensus view of the risk scenarios, probabilities and consequences. This method also builds broad support for a prediction because all stakeholders or experts had an opportunity to contribute.

A third approach to eliciting estimates from experts is to use various paired comparison techniques. These techniques combine experts' opinions about risk and probabilities and allow the project team to test if a specific expert's opinion should be included or omitted from the model. There are a number of models within pair comparisons, such as the Thurstone and Bradley-Terry models, but each model uses quantitative techniques to evaluate the credibility of expert judgment. Bayesian techniques can also be used to test the biases and accuracy of expert judgment.

The Brier score is useful for scoring predictions made by experts. The scoring mechanism is weighted such that experts receive a higher score for an accurate prediction made with high confidence than an accurate prediction with low confidence. Similarly, the Brier score penalizes sandbagging, in which an expert provides an unreasonably large range for their 90% confidence interval. The Brier score is compares the probability of the forecast ( $f_t$ ) to the actual outcome ($o_t$ ) such that:

$$BS = \frac{1}{N}\sum_{t=1}^{N}(f_t - o_t)^2$$

A perfect score is 1. An expert's combined score is the average of scores on individual predictions. Experts may be better calibrated for some predictions than others and the Brier score can help identify in which areas an expert's opinion may be more credible.

Applying quantitative rigor to the data elicited from experts will produce better results than relying solely upon the expert's raw responses. When experts provide ranges for probabilities, the project team can use techniques like PRA and Monte Carlo to test the sensitivity of the project to specific risks. Understanding which risks affect the model helps the project team to determine how to prioritize the risks.

*3.4. Risk Response Planning*

The project team will have more data for events that happen frequently and having a better understanding of a risk allows the project team to allocate that risk better, preferably to the party best able to manage that risk. For frequent, low consequence events, the project team should accept the risk as part of doing business.

For each risk identified in the risk assessment, the project team should decide on one of four options to manage the risk: • Accept: Conclude that the cost of mitigation exceeds the value of mitigation • Mitigate: Take steps to reduce the risk, such as providing training or installing safety protocols • Transfer: Reallocate the risk to a third party, such as an insurance agency or contractor better able to mitigate the risk • Avoid: Change the project such that the risk no longer poses a threat to the project

For construction mega-projects, the team should seek to transfer as much risk as practicable to third parties. Sharing risks with contractors and vendors helps align the incentives of the broader project team. Contracts can be used to transfer risk from the project team to other parties.

Conducting risk assessments early and often is the best way to identify risks which should be avoided while the cost of project changes is small. Changing a project's scope or requirements once construction has begun may cost more than the risk the project is seeking to avoid. However, if risks are clearly identified in the early gates of the stage-gate process, the project team can find inexpensive ways to avoid certain risks. This is especially important for risks affecting the critical path because a delay in a critical path item will have reverberations throughout the project.

For mega-projects, the events that pose the greatest danger are low frequency and high consequence. Such events include regime change, war, famine, and widespread civil unrest. Unfortunately, these are precisely the type of events which cause the most difficulty for experts to accurately forecast (Cutler and Zeckhauser, 2004). However, there are organizations which sell insurance against low probability, high risk events. It is worth consulting these organizations to have an estimate of the price to transfer risk. If a proposed risk mitigation step exceeds the cost of insurance, then the project team should consider buying insurance and proceeding without mitigating that risk.

3.4.1. Measuring Severity

At times it is helpful to consider risks on an ordinal raking scale. This can help focus attention on the most severe risks.

The non-linearity of this classification system is designed to demonstrate utility for the company such that an ordinal change from 1 to 2 is less server than an ordinal change from 4 to 5 (Galway, 2004). Because the classifications are ordinal, project teams should exercise extreme caution when adding, subtracting or multiplying these numbers like cardinal numbers (Cox, 2008). The project team must be clear that resulting scale is none linear, meaning the difference in risk between 19 and 20 is not the same as the difference between 20 and 21.

| Severity Name | Delay to Schedule | Additional Cost | Examples |
|---|---|---|---|
| Catastrophic | Over 12 months | ≥ $50 million | Force Majeure |
| Major | Over 6 months | ≥ $20 million | Labor dispute leading to strike |
| Substantial | Over 3 months | ≥ $10 million | New regulatory requirements |
| Moderate | Over 1 month | ≥ $5 million | New Permitting requirements |
| Minor | Over 1 week | ≥ $1 million | Supply chain disruption |
| Near Miss | No delay | Additional cost | Event did not occur |

*Table 2: Severity Classification System*

<u>3.4.2. Measuring Likelihood</u>

How likely an event is to occur is based on the probability that event will occur in any one trial times the number of trials. Events with small probabilities of occurrence in a single trial could still be likely if that event happens frequently.

| Probability | Negative Outcome Is Expected |
|---|---|
| P(x) = .0001 | Once in 10,000 instances |
| P(x) = .001 | Once in 1,000 instances |
| P(x) = .01 | Once in 100 instances |
| P(x) = .1 | Once in 10 instances |

*Table 3: Probability Classification System*

In addition to probabilities, the project team needs a consider the frequency of events. This can be standardized to a 12-month period. The team can use historic data to count the frequency of certain events, such as the annual average of bills passed or court decisions which could affect operations. The chart below is notional. To the extent possible, the frequency should be based on actual data. Low probability events which happen frequently should be addressed differently than low probability events which occur infrequently.

| Frequency | Event Is Expected to Occur | Example |
|---|---|---|
| .5 | Once every two years | Political election |
| 1 | Once a year | Labor dispute |
| 4 | Once a quarter | Shareholder reporting |
| 12 | Once a month | Local permitting decisions |
| 52 | Once a week | Shipments arriving |

*Table 4: Frequency Classification System over One Year Time Horizon*

There are two levers for risk management within the likelihood parameter. The project team can seek to change the frequency of trials and the team can seek to change the probability of a negative outcome. Reducing either parameter will reduce the risk. For example, the frequency of elections is fixed but the project team can seek to decrease the probability that a hostile candidate wins. The probability that a labor dispute is negative is high, but the team can seek to decrease the frequency of labor disputes.

*3.5. Risk Matrices*

The results of the Monte Carlo and other risk assessments can be displayed visually using a risk matrix. The various combinations of severity and likelihood (i.e. the boxes of the matrix) provide an easily understandable summary of the risks. In general, risk matrices provide a high level overview of the risk assessment. It is possible to create a more detailed risk matrix which will provide more fidelity.

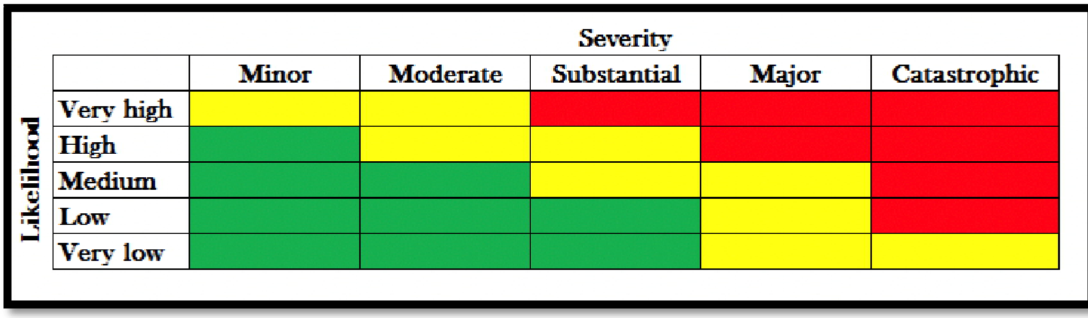


*Figure 3: Simplistic Risk Matrix*

A simple 5x5 risk matrix can mislead risk managers into thinking of risks on an ordinal scale when the values are not linear. A simplistic risk matrix can be worse than useless (i.e. harmful) if it is use as a sole decision making criterion. The matrix can be useful in drawing attention to general categories of risk that should be avoided, such as very likely events that would have catastrophic consequences. However, the project team should not impute to a risk matrix the analytical power of other risk assessment tools such as Monte Carlo simulation (Lund, 2008).

Given the limitations of the risk matrix and it should be used as one aspect of a decision, not the sole determining factor (Cox, 2008). If not considered carefully, the risk matrix can produce inconsistent results when two risks with the same combine risk score are treated differently within the matrix. That is partly driven by the practice of converting cardinal data to an ordinal scale.

*3.6. Modeling Failure*

Failure Modes and Effect Analysis (FMEA) is another tool for prioritizing risks. This model considered the chance of a failure ($S_f$) with the chance of detection ($S_d$) and the severity of a failure ($S_f$). The product $S_f S_d S$ is the risk priority number (Gilchrist, 1993). FMEA can be applied in the design phase of a project to prevent costly risks in future phases.

A fault tree analysis provides a systems approach to identifying component risks and how those risks affect the overall system. The drawback of fault trees is that like PRAs they can be expensive to produce. However, given the value of a mega- project, the expense of such an analysis is almost always justified. If cost becomes a major consideration before a fault tree is created, it is possible to change the level of detail modeled in the analyses such that a less detailed model is less expensive to produce (Lee et al., 1985).

*3.7. Model of the World*

The combined qualitative and quantitative data are used to generate a Model of the World (Stamatelatos, 2000). Once this model is created, should be tested using historical data. Once calibrated, the model can run Monte Carlo simulations. One of the biggest dangers with project risk is that the components may not be independent, meaning a single event could pose several risks to the project. The correlation should be included in the Monte Carlo simulations.

The Monte Carlo simulation can show the sensitivity of the project risks to various factors. By running tens of thousands of trials, the project team can gain insights into the possible outcomes for projects which are otherwise considered bespoke. This simulated data can show patterns of interaction and complex interdependence between variables. Knowing that those relationships exist will help the project team better mitigate those risks. Such a simulation can also reduce heuristic bias which may have been introduced through expert opinions.

Ultimately it is the quantification of risk that allows the project team to compare risks with their associated costs and determine how to mitigate those risk (Pate´-Cornell, 2002). Using quantitative analysis from the PRA and qualitative data that has been transformed through quantitative provides the clearest picture on how the project should allocate scarce resources in the most efficient manner possible (Pate´-Cornell, 2002).

## 4. Risk Mitigation Toolset

The preceding steps are designed to identify, quantify and understate the risks a project faces throughout the project lifecycle. Risk management, on the other hand, uses the risk analysis to "devise management strategies to reduce or ameliorate risk" (Galway, 2004).

The purpose of risk management, then, is to take steps that decrease the probability of negative events that affect the project's schedule, cost or scope. Each objective should hold equal value for the project, however data show that line engineers tend to focus their time on mitigating schedule and quality (technical) risks and play significantly less attention to cost risks (Smith et al., 2009). The same research shows that prospect theory plays a role in how line engineers assess risk such that they are risk seeking for loses and risk averse for gains.

There are two main levers a project team can use to reduce risk: reduce the likelihood of a negative event and reduce the consequences of a negative event. Project engineers tend to focus on reducing the likelihood over reducing the consequence (Smith et al., 2009). However, this can lead to suboptimal outcomes. For large scale, non-routine construction projects, the likelihood of component failure should be fairly certain. For example, partially transferring risk through contractual tools such as joint ventures or building redundant systems are two effective ways to reduce the consequence of an event without reducing the likelihood of that event.

*4.1. Reviewing the Completeness of the Plan*

After the risk analysis and management plan have been created, these documents should be checked for completeness. This additional step is designed to ensure the analysis and plan is robust and has considered all practicable risks (Hubbard, 2009).

- Internal (functional) completeness: The project risk management should include perspectives from all the project sub- teams. A subteam of the project, such as the IT or law departments, bring additional perspective to the overall risks a project faces. Similarly, workers at all levels of the project should contribute to the risk management plan. There is evidence that workers and managers assess risk differently and including risk analysis from different levels within a project can identify new potential risks (Smith et al., 2009).
- External completeness: The project team should also elicit risk information from groups outside the project. Vendors, contractors and government agencies often have much more experience with the risks in a particular location than the project team will have. These external groups will also have a different perspective on how risks can be mitigated. Engaging with those external groups could review better ways to transfer project risk to the parties best able to bear the risk.
- Historical completeness: Risk managers should consider the breadth of "worst case scenarios" to include tsunamis, plague, economic depression and other major events. Data exists on these worst cases because some project somewhere has encountered each of these worst-case events. Even though the number of observations may be low, having real data can reduce uncertainly significantly.
- Combinatorial completeness: Risk managers should consider the consequences of several bad events happening together. Often the probability of negative events is not independent. Bayesian analysis can provide some insight into the probability of one event given the occurrence of another event. For large scale construction projects, a Markov Process may be more instructive on the probabilities of the project moving through certain discrete phases. The goal of checking combinatorial completeness is to understand which events are correlated and the possible consequences of multiple negative events happening concurrently.

*4.2. Unknown Unknowns*

Even with an extensive and iterative review process, there will be risks which the project team does not account for. The project team should allocate time and budget to address contingencies. As events occur, the project team should capture the learnings from that event for use in future projects. This process for sharing global learnings is possibly the least expensive and most valuable risk management step the team can take.

## 5. Conclusion

Risk management actions should demonstrably reduce project risks. Mitigation steps should be continually assessed to ensure that the mitigation is effective and worth the cost/effort. Without vigilance in reassessing a risk management plan, it can become "worse than useless" (Hubbard, 2009).

Project risk identification should be the summation of attendant risks in subsections of the project plus the interdependence of risk between those subsections. Project risk management should evaluate each risk and determine how best to mitigate that risk. Equal weight should be given to risks that affect the project's schedule, cost and scope.
Analytical frameworks for risk assessment can help clarify and prioritize the risk. Once the risks are identified and analyzed, the project team can determine how best to approach the risks by accepting the risk, mitigating it, transferring it or avoiding it.

Thorough and thoughtful risk management is as important to the success of an oil and gas development as the structural engineering and the geological science. Risks to the project can prevent the project from achieving its objectives and cost the sponsor companies billions of dollars. This guide is designed to help project teams use sophisticated, modern techniques to improve the probability of success with each mega-project.

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