Risk Management Plan

2019-004.6

Approval Date

Approval		Date
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Change Log

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Contents

1. Purpose

The purpose of this document is to define the risk management processes, based on standard best practices, that is used for the IceCube Upgrade project. This document details the responsibilities and process of the Risk Management procedures adopted by IceCube Upgrade, and are based on the U.S. General Accounting Office cost estimating guide (1) , the National Science Foundation's Research Infrastructure Guide (2), and the ANSI-standard and industry best-practice "Project Management Body of Knowledge" (3).

2. Introduction

2.1. Overview and Terminology

A **risk** is a future event that may potentially have consequences or **impacts** on the cost, schedule, technical scope, quality, or some other objective of a project. **Risk management** is a forward-looking, continuous, and iterative process for managing risk in order to achieve the project goals. We consider three types of risks:

- **threats** have negative impacts;
- **opportunities** have positive impacts; and
- **uncertainties** may have either negative or positive impacts.

The uncertain nature of risks is captured by an estimated **probability** of the risk event occurring and the ranges of the potential impacts. Risk management reduces the probability and impacts of threats – and increases them for opportunities – by building risk **mitigation actions** into the project plan to address risks before they happen. When risks cannot be adequately mitigated, **risk response plans** are developed to cope with risk events should they happen. A **risk trigger** identifies the risk symptoms or warning signs, and indicates that a risk has occurred or is about to occur. The risks, probabilities, impacts, mitigations, and response plans are recorded in the **risk register** (4) .

An overall **risk ranking** is assigned to each risk depending on its position in a two-dimensional **risk matrix** of probability vs. impacts. This ranking reflects the project's risk appetite and determines what level of oversight is required for the risk event.

The aggregate impacts of risks are assessed, using a Monte Carlo (MC) model based on the resource-loaded schedule (RLS) and risk register. For risks that cannot be mitigated, the cost impacts are covered by **risk-based contingency**. Similarly, potential delays from risks are addressed by including **schedule contingency** prior to key milestones in the schedule, notably the project's required completion date.

Risk contingencies are determined at a **70% confidence level**, which implies that on average seven out of ten projects will be completed within cost and on schedule. In exceptional cases, a different confidence level may be used, subject to agreement between the project and NSF

.
Two additional types of contingency are used by the project to help manage risk:

1. **Cost Estimate Uncertainty** contingency covers uncertainties in base costs of materials, equipment and labor; and
2. **Scope Contingency** refers to scope that could be dropped that, while impacting the science, would not jeopardize the overall success of the project. A detailed discussion of scope contingency, both up and down, along with the scientific impact, is documented in the Scope Management Plan (5).

2.2. Key Products of Risk Management

From the National Science Foundation's Research Infrastructure Guide (2), there are three key products of Risk Management:

1. A **Risk Management Plan** that details how the project follows standard risk management processes and practices
2. A **Risk Register** to document identified risks
3. A **Quantitative Risk Analysis** to determine the risk exposure of the project, and the amount of contingency needed to control the risks.

3. Risk Processes

The processes described in this document build upon the NSF Research Infrastructure Guide (2), and the ANSI-standard and industry best-practice "Project Management Body of Knowledge (PMBOK)" (3). These processes are shown in the context of the overall project planning process in Figure 1; the numbers associated to the processes denote the corresponding sections in the PMBOK guide. These risk management processes, which are described in detail in this document, are as follows:

- **Plan Risk Management** [PMBOK, section 11.1];
- **Identify Risks** [PMBOK, section 11.2];
- **Perform Qualitative Risk Analysis** [PMBOK, section 11.3];
- **Perform Quantitative Risk Analysis** [PMBOK, section 11.4];
- **Plan Risk Responses** [PMBOK, section 11.5]; and
- **Monitor and Control Risks** [PMBOK, section 11.6].

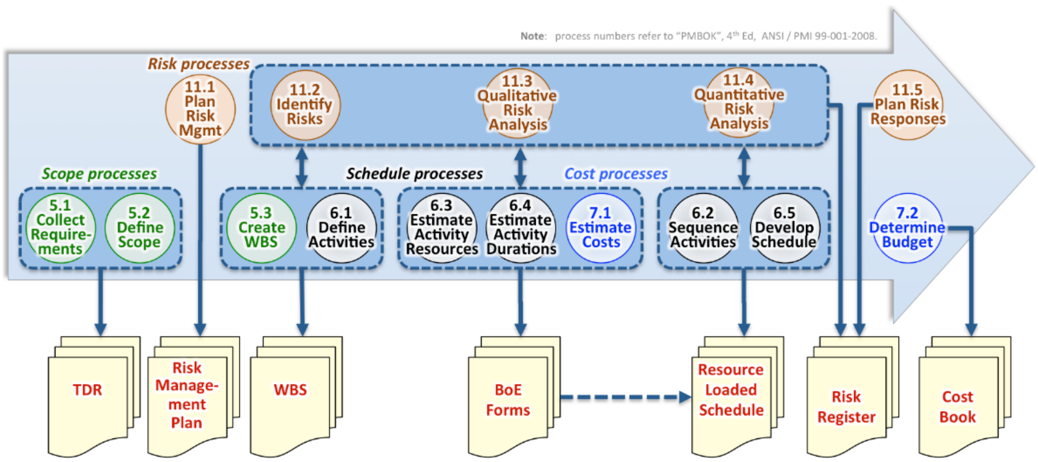

Figure 1 Risk management processes in the context of the overall planning process.

3.1. Plan Risk Management

The Plan Risk Management process [PMBOK, section 11.1] is based on the processes described in this document, and shall take into account existing procedures, standards and policies related to risk management in other areas such as:

- environment, safety and health (ES&H);
- scientific integrity and reputational risk;
- political, funding, and market risk;
- legal and accounting compliance; and
- IT security and data protection

3.1.1. Risk Management Plan

The primary output of the Plan Risk Management process is the Risk Management Plan, which describes how risks will be identified, analyzed, monitored, and managed, along with the roles and responsibilities for managing risks. The risks themselves are collected and documented in the Risk Register (4).

3.1.2. Roles and Responsibilities

The IceCube Upgrade Project does not have a dedicated Risk Manager, therefore the duties that would typically be undertaken by a Risk Manager are shared between the Project Manager, Technical Coordinator, and Project Controls, namely in establishing the project's processes and systems for identifying risks, documenting them, analyzing their probabilities and impacts, developing mitigations and response plans, and monitoring them. They are responsible for maintaining the risk information in the risk register and performing a project-wide risk analysis using MC or other techniques to aggregate cost and schedule impacts for the entire project. They also coordinate the preparation of risk reports to the combined Risk Management and Change Control Board and project oversight bodies. The exact breakdown of the duties is listed below.

Project Manager (PM) Ultimately responsible for all aspects of project risk management

- Establishes the project's processes and systems for identifying risks, documenting them, and analyzing their probabilities and impacts
- Assigns a **Risk Owner** to each risk (see below)
- Reports on risks to oversight bodies

Technical Coordinator (TC)

- Assists the PM and the project team in all aspects of risk management.
- Takes responsibility in documenting mitigation and response plans for risks, and monitoring them
- Maintains the risk information in the risk register

Quality Manager (QM)

- Tracks risks and risk triggers
- Works with Risk Owners to ensure consistency of risk assumptions across the project
- Alerts CCB to upcoming risks / risk triggers

Project Controls (PC)

- Performs project-wide risk analysis using Monte Carlo techniques to aggregate cost and schedule impacts for the entire project.

Risk Owner

- Each risk has a risk owner, who is typically the subject matter expert (SME) who identified the risk. The risk owner helps to analyze the risk and develops and executes mitigation and response plans.

Combined Change Control and Risk Management Board

The Combined Change Control and Risk Management Board is chaired by the Project Manager and consists of the PM, TC, PC, the Project Engineer, the Project Safety and QA/QC officer, the Logistics coordinator, the Associate Director for Science and Instrumentation, and the WBS L2 managers. Additional staff may be invited as needed for specific topics. The board meets weekly; risks are reviewed at least quarterly.

L2 Managers and CAMs

WBS Level 2 Managers and Cost Account Managers are responsible for working with their teams and other stakeholders to: identify risks to their subproject; assess their probabilities and impacts; and develop and execute risk mitigation and response plans. L2 managers and CAMs report on risk-related issues to the Combined Change Control and Risk Management Board.

National Science Foundation

The National Science Foundation Program Officers ensure that the Project has established an appropriate risk management process, monitors its implementation, and affirms decisions of the Change Control and Risk Management Board. The NSF approves the use of risk contingency when the amount exceeds the spending authority of the PM.

Table 1 shows the risk management responsibility assignment matrix.

Process / Responsible	**Project Manager**	**Technical Coordinator**	**Project Safety/QA/QC Officer**	**L2 or Control Account Manager**	**Project Controls**	**Risk Owner**	**NSF**
Plan Risk Management	Performs	Contributes	Contributes	Contributes	-	Contributes	Reviews
Identify Risks	Accountable	Contributes	Contributes	Contributes	-	Contributes	Reviews
Perform Qualitative Risk Analysis	Accountable	Contributes	Contributes	Contributes	-	Performs	Reviews
Perform Quantitative Risk Analysis	Accountable	Contributes	Contributes	Contributes	Performs	Contributes	Reviews
Plan Risk Responses	Accountable	Contributes	Contributes	Performs	-	Performs	Reviews
Monitor and Control Risks	Accountable	Contributes	Performs	Performs	-	Performs	Reviews

Table 1 Risk Responsibility Matrix for the IceCube Upgrade Project.

3.2. Identify Risks

The "Identify Risks" process [PMBOK, section 11.2] assesses all aspects of the project to produce a comprehensive list of risks, including threats, opportunities, and uncertainties. To maximize the benefits of risk management, risk identification starts very early in the project's lifecycle and continues throughout the project.

Risks are identified using a number of techniques. Project documents are reviewed for possible sources of risk, including the Key Assumptions document, the cost basis-of-estimate (BoE) documents, the work breakdown structure (WBS), and the resource-loaded schedule (RLS). Additional risks are identified through brainstorming, interviews with SMEs, risk workshops involving project members and external experts, and lessons learned from the IceCube Gen1 project.

The "Identify Risks" process involves all stakeholders. Team members are encouraged to identify risks bottom-up. A complementary top-down analysis, led by the project's management, identifies risks of a general cross-cutting nature.

Risk Breakdown Structure

To help ensure full coverage of the risk spectrum, the project is guided by a Risk Breakdown Structure (RBS), shown in Figure 2, which summarizes a broad range of common risk areas. The project will also explore additional areas of risk that are peculiar to the project.

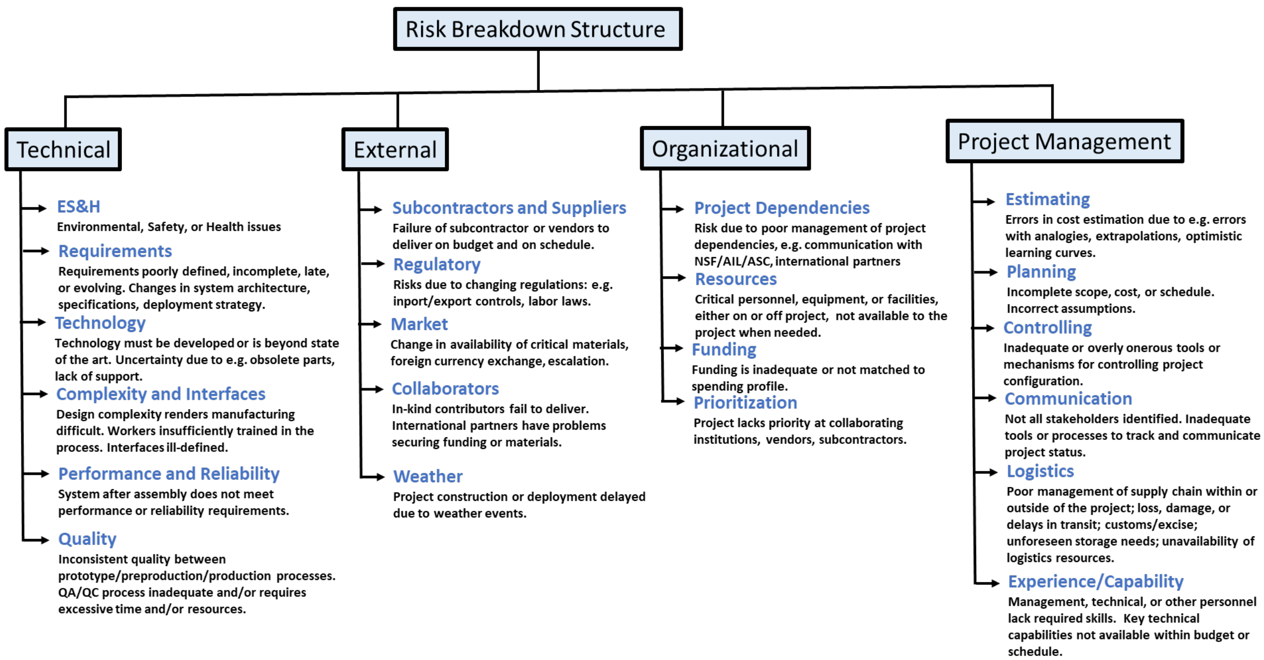

Figure 2 Risk Breakdown Structure Categories. These are broad categories to guide the Risk Identification process to ensure all risks are captured.

3.2.1. Risk Register

The output of the "Identify Risks" process is a set of risks that is documented in the IceCube Upgrade risk register. Each risk is characterized in the risk register by the following metadata:

- Unique risk ID and risk name;
- A summary description phrased so as to emphasize cause and effect:

  IF <RISK EVENT> happens THEN <IMPACTS> jeopardize <OBJECTIVES>;
- Risk type, risk area (RBS), risk owner, and WBS;
- Risk status, start and end date period of risk validity, and conditions for closing the risk;

- Risk probability and technical, cost, and schedule impacts (and the basis for these estimates);
- Activities in the RLS that are impacted by the risk, and the risk trigger or causal factors;
- Risk mitigations in the base plan, and risk responses to be executed if the risk occurs; and
- Miscellaneous notes and links to supporting information.

The risk register determines the risk rankings based on the project's risk ranking matrix and the risk probability and impact values.

3.3. Perform Qualitative Risk Analysis

The "Perform Qualitative Risk Analysis" process [PMBOK, section 11.3] estimates the probability of the risk occurring and the impacts on cost, schedule, and technical performance. The risk probability and impacts are then used to rank the risks.

Estimating Risk Probabilities and Impacts

The probabilities and impacts of risks are estimated by subject matter experts (SMEs) and reviewed by other experts and project management. Estimates may be based on prior experience, extrapolations from similar situations, expert judgment, or industry-standards. The estimated risk probability for each risk is characterized by a range of values as shown in Figure 3.

Technical risk impacts are determined by SMEs, using results from engineering risk assessments and the project's technical requirements, specifications, and quality criteria of the deliverables. In the worst case, high impact technical risks may jeopardize the project's Scientific Objectives.

Estimates of the **cost risk impacts** include the direct cost due to the risk event and the costs of risk response plans.

To determine the **schedule impacts** of risk events, the directly impacted activities in the Resource Loaded Schedule are identified and the risk delay is estimated, including the risk event itself and the risk response plans. The schedule impact is determined at the level of the activities directly impacted by the risk. These activities may or may not be on the critical path, therefore the consequences of the risk on the overall project schedule should be assessed as an *output* of the Quantitative Risk Analysis process, described below.

Risk impacts may be correlated. For example, if a risk event results in the need for rework, the duration of the rework and the labor cost are often correlated. There may also be cases in which a risk has a correlated impact on many activities in the RLS.

Risk Ranking

A matrix of risk probability vs. impacts, shown in Figure 3, is used to rank the risks. Figure 4 shows the thresholds in cost and schedule impacts for the various impact levels. For threats the impacts are negative (cost increase or schedule is delayed) and for opportunities they are positive (cost saving or schedule is advanced). Risks are assigned to bins of probability and impact, which have non-linear spacing to cover a broad dynamic range.

Probability	Impact Level				
	Very Low	Low	Moderate	High	Very High
Very High (75%-95%)	**Moderate Rank**	**Moderate Rank**	**High Rank**	**High Rank**	**High Rank**
High (50%-75%)	**Low Rank**	**Moderate Rank**	**High Rank**	**High Rank**	**High Rank**
Moderate	**Low Rank**	**Moderate Rank**	**Moderate Rank**	**High Rank**	**High Rank**
Low (5%-25%)	**Low Rank**	**Low Rank**	**Moderate Rank**	**Moderate Rank**	**Moderate Rank**
Very Low (1%-5%)	**Low Rank**	**Low Rank**	**Low Rank**	**Low Rank**	**Moderate Rank**

Figure 3 Probability and Impact Matrix for risk scoring.

	Very Low	Low	Moderate	High	Very High
Technical Impact	No impact	Somewhat substandard	Significantly substandard	Extremely substandard	Scientific objectives in jeopardy
Cost Impact	Less than $10k	$10k - $50k	$50k - $250k	$250k - $1M	> $1M
Schedule Impact	Less than 1 week	1 month	3 months	6 months	Greater than 6 months
Scope Impact	Scope decreases barely noticeable	Minor areas of scope affected	Major areas of scope affected	Scope reduction unacceptable to sponsor	Project item is effectively useless
Quality / Performance Impact	Quality / performance degradation barely noticeable	Only very demanding applications are affected	Quality / performance reduction requires sponsor approval	Quality / performance degradation unacceptable to sponsor	Project item is effectively useless

Figure 4 Risk Impact Scoring. These are the NSF / Project agreed upon definitions of impact scores with respect to cost or schedule.

The implications of the risk rankings are as follows:

- **High Rank** risks can lead to the failure to complete major deliverables within cost, schedule, quality, or other constraints and may jeopardize the project's scientific objectives. All high-rank risks must have well-developed mitigation or response plans.
- **Moderate Rank** risks can have a significant impact on the ability of the project to deliver all aspects of the project scope in a timely and cost-effective manner, but they are not expected to jeopardize the project's scientific objectives. All medium-rank risks must have mitigation or response plans.
- **Low Rank** risks have a modest technical, cost or schedule impact that will not affect the completion of the project. Low-rank risks should generally have mitigation or response plans, although this is not an absolute necessity, particularly if the risks are not imminent.

Risks that are below low rank are assigned a "negligible" rank and are not included in the quantitative risk analysis. They are monitored in case their probability or impacts increase in future.

The output of the "Perform Qualitative Risk Analysis" process is a list of high-, medium-, and low-rank risks, documented in the risk register with preliminary estimates of their probabilities and impacts. All risks are analyzed in more detail in the "Perform Quantitative Risk Analysis" process.

3.4. Perform Quantitative Risk Analysis

The "Perform Quantitative Risk Analysis" process [PMBOK, section 11.4] quantifies in more detail the impacts of individual risks and aggregates them stochastically to determine the impacts of all risks on the project's cost and schedule objectives. The aggregated impacts are typically estimated using a MC simulation of all risks (threats, opportunities, and uncertainties), that includes all the activities in the RLS and the associated schedule logic. The MC model analyzes the range of costs and key milestone finish dates to ensure that the project can be delivered within cost and on time at a high level of confidence. The results of the risk analysis are documented in this section.

Risk Monte Carlo Analysis

Risks identified in the risk register are used as inputs to the @risk Monte Carlo risk simulation tool. The probability of any risk occurring during the project execution is calculated as a flat distribution between the low and high ranges from the first column of Figure *3*. The risk cost impact is a pert function with minimum, maximum, and most likely values taken from the risk register.

Risk-based Cost Contingency

The total cost as defined above for all discrete risk threats and opportunities (high-, moderate- and low-ranked) is used to determine the “risk-based contingency” budget, at a high confidence level. This is distinct from the “cost estimate uncertainty contingency”, which allows for the uncertainties in labor and equipment costs.

Results

Figure 5 and

Figure 6 show the overall Monte Carlo results for the risks, and the “tornado plot” of risks that most impact the resulting distribution. This represents 79 distinct risks and 1 opportunity in the most recent risk register.

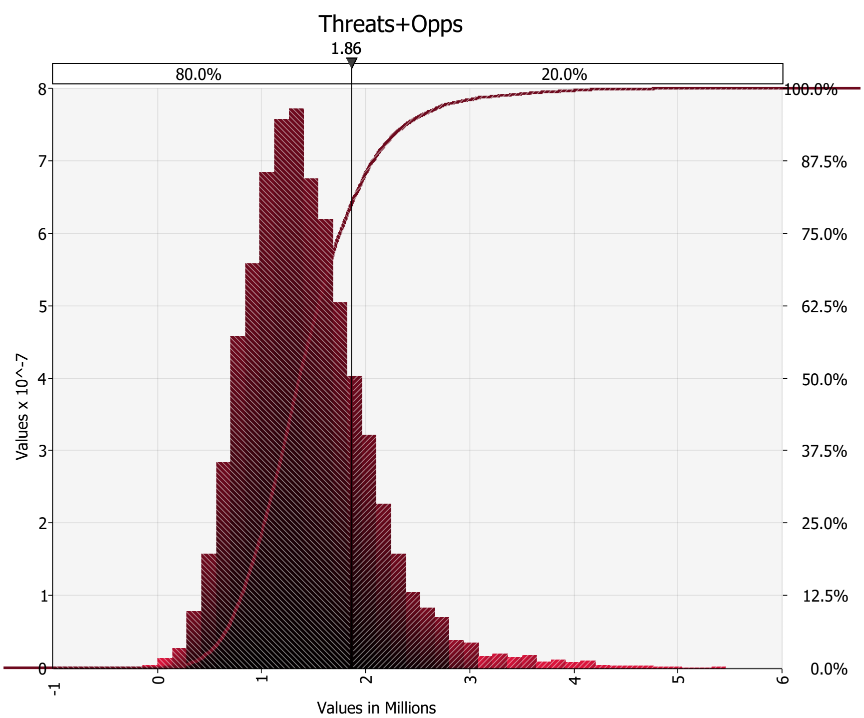

Figure 5 Monte Carlo distribution of Upgrade risk probabilities and risk exposures.

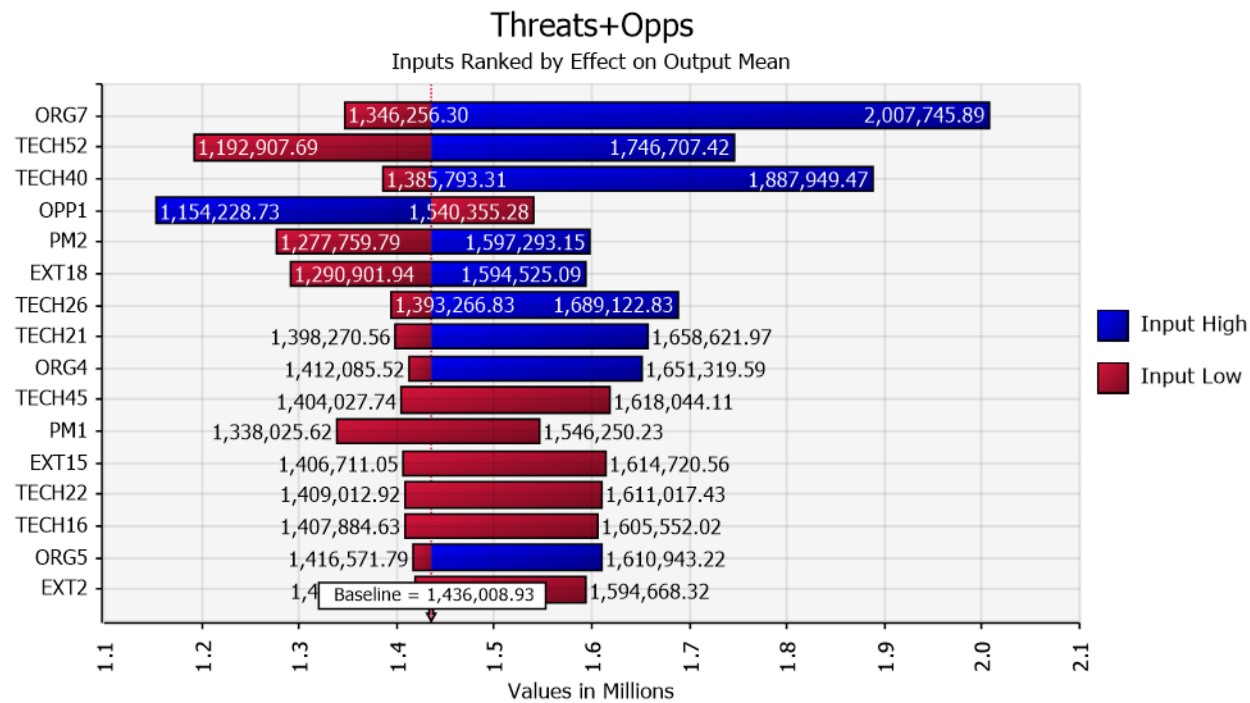

Figure 6 "Tornado plot" of the highest impact risks. For definitions of all risks, see the Upgrade Risk Register (4). The top 10 risks are shown in

Table 2.

Tag	Description	How cost impact was estimated
ORG7	Driller talent acquisition and retention	Cost impact estimated by increasing pay per driller per season
TECH52	Breakout Cable Costs	These are in-kind, but may exceed the amount of in-kind funding available. Risk exposure is estimated by initial bids from companies who have not yet seen the prototype cable.
TECH40	Main Cable Costs	These costs are estimated by costs incurred if the main cable prototype does not pass mechanical testing, and we have to switch main cable vendors.
OPP1	Contributed drillers	All drillers are costed on project. This risk represents the opportunity that the collaboration contributes drillers. The savings is estimated by 50k / driller / season and up

		to 10 contributed drillers over the 3 field seasons.
PM2	Risk of losing key personnel	Cost is estimated by a 20% increase in salaries on 10% of key personnel from PY5-PY8
EXT18	Unavailable parts for mDOM main board means the board has to be redesigned	Design work is in-kind, however firmware and software changes could be significant. The on-project risk exposure is estimated at 1.5 software engineer FTEs.
TECH26	Failure of a harness or rigging element that would result in undeploying partially the string and swapping instrumentation/BCAs.	Hole may need to be re-drilled if undeployment took long enough for the hole to be significantly closed. Cost estimated for additional fuel and labor.
TECH21	A majority of the EHWD equipment has been stored/cold-soaked for 6+ years at the South Pole. Risk of old EHWD equipment failure.	Cost estimated using Offseason equipment budget to address (80k) plus additional on-ice work in FS2 ~ 2 week delay
ORG4	Serious FS3 injury or incident occurance halts on-ice activities until full accident investigation	Assumes a delay of ~ 1 month for the on-ice drill season. Minimum is 2 weeks, maximum is missing the full drill season.
TECH45	Because MCA procurement is not finalized, we may have insufficient bandwidth to transmit all data to ICL using the planned cables and comms protocol, which will require additional software or firmware engineering and may reduce science capabilities.	Add engineering effort - 1 FTE yr - to develop better communications protocol. Development schedule permits completion before deployment

Table 2 Summary of top 10 risks for the Upgrade Project. For the full definition see the Upgrade Risk Register (4).

Table 3 shows the amount of contingency cost estimated to cover risks at the 70%, 80%, and 90% confidence level. For the Upgrade project, we use 80%, thus the total additional contingency needed to cover the identified risk (threats + opportunities) events is about $1.9M.

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	Confidence Level		
	70%	80%	90%
All Threats + Opportunities	$1,663,149	$1,861,241	$2,170,439

Table 3 Overall cost impact of identified risks for various confidence levels. For the Upgrade Project, we are using the 80% confidence level.

3.5. Plan Risk Responses

In the "Plan Risk Responses" process [PMBOK, section 11.5] risks are assigned to a risk owner who works with the project team and other stakeholders to develop a risk handling strategy that is documented in the risk register. The main strategies for addressing risks are described below.

Risk Mitigation / Enhancement
Risk mitigations are actions that are included in the baseline plan to reduce the likelihood or impact of a risk ***threat*** before it happens. The cost, schedule and other impacts of the mitigation actions should be acceptable when compared to the probability-weighted impacts of the risk, should it occur.
Example: development and testing of pre-production items before commencing full production.

Risk enhancement involves taking actions to increase the likelihood or impact of a risk ***opportunity*** before it happens.

Risk Avoidance / Exploitation
Risk avoidance is the elimination of a risk ***threat*** by making changes to the baseline plan. The cost, schedule, and other impacts of the changes to the baseline should generally be less than the probability-weighted impacts of the risk, should it occur.
Example: risk of a single vendor failing is avoided by placing contracts with two vendors, with options to deliver the full amount should one vendor fail.
Risk exploitation involves changing the baseline plan to ensure that a risk ***opportunity*** occurs.

Risk Transfer / Sharing
Risk transfer does not decrease the probability of a risk ***threat*** but it does shift responsibility for the impacts to a third party, generally at some cost to the project.
Example: the cost risk for replacing items damaged in transit is transferred to an insurance company and the cost of the insurance premium is borne by the project.
Risk sharing is the splitting of a risk ***opportunity*** into parts that yield benefits to several parties, with a clear delineation of associated responsibilities and benefits.

Risk Acceptance
Risk acceptance for threats implies nothing is done to eliminate, mitigate or transfer the risk before it happens. This strategy may be used when there is no effective mitigation strategy, when the cost of mitigation outweighs the risk impact, or when the potential risk event is still in the distant future. With this strategy the baseline plan is unchanged and no mitigation costs are incurred. In general, risk response plans are required that can be executed if the risk event occurs. These require the expenditure of risk-based contingency.
Risk acceptance for opportunities is an acknowledgement that something beneficial may happen without taking action to increase the likelihood or impact.
Example: accepting uncertainties in future currency exchange rates for foreign procurements.

Residual and Secondary Risks

There may be **residual risk** after the primary risk has been dealt with if the risk handling strategy is not completely effective. Similarly, actions taken when handling a risk may themselves trigger a **secondary risk**. Residual and secondary risks should be assessed and, if they are found to be significant, they should be addressed using the same approach that is used for primary risks. Often the residual and secondary risks are modest, it is accepted that they may happen, and their cost and schedule impacts are taken into account when assessing the primary risk.

3.6. Monitor and Control Risks

The Monitor and Control Risks process [PMBOK, section 11.6] includes the monitoring and updating of identified risks and their triggers, the implementation of risk response plans, the management of residual and secondary risk, the retirement of risks that are no longer current, and the identification of new risks. It also includes the continual evaluation and improvement of the risk management process.

High- and medium-rank risks are monitored by the Project Manager, who reports on them to the IPT on a regular basis. The Project Manager, the Technical Coordinator, and the L2 managers are responsible for leading the risk handling activities, together with the risk owner. Low Rank risks are monitored and handled by the L2 managers and risk owners, who report on them to the combined Change Control and Risk Management Board on a regular basis.

The Monitor and Control Risks process includes the tracking and usage of risk contingency. Within the project, only the Project Manager may authorize the use of risk contingency funds. This is done with the approval of the National Science Foundation Program Officers according to the contingency usage thresholds specified in the IceCube Upgrade Project Execution Plan (6).

Risk Reporting

The Technical Coordinator assists the Project Manager and the Change Control Board by ensuring that the risk register is accurate and up-to-date, and by preparing risk reports that address, for example: status of open risks; proposed new risks; changes to existing risks; and results of risk analyses. The PM and TC report on matters of risk to the project's oversight bodies such as the Integrated Project Team, and reviews.

Process improvement

Project risk reviews and workshops are carried out as required to ensure that the risk analysis and risk management processes are current and effective. This may lead to updated risk assessments and refinements of the risk management process.

Approvers for IceCube Upgrade Risk Management Plan 2/6/2020

Title	Assigned To	Status	Priority	Date and Time	Outcome
IceCube Upgrade Risk Management Plan	Mike Zernick	Completed	(2) Normal	2/3/2020 11:00	Signed
IceCube Upgrade Risk Management Plan	Farshid Feyzi	Completed	(2) Normal	2/4/2020 11:00	Signed