ICECUBE
UPGRADE

Risk Management Plan

2022-004.7

	Approval	Date
Project Director	Vivian O'Dell	
Project Manager	F. Feyzi	
Quality & Safety Manager	M. Zernick	
Project Technical Coordinator	Michael DuVernois	

Change Log

Revision	Description: Author	Date
0	Original document: M. Zernick	1/31/19
1	Added Monte Carlo reference: M. Zernick	4/09/19
2	Added cost tracking, contingency, and scope planning: F. Feyzi	10/1/2019
3	Updated per comments received from NSF: F. Feyzi	02/03/2020
4	Expanded and updated for NSF Rebaseline. Risks, impacts, and contingencies need to be updated with new qualitative and quantitative analyses. V. O'Dell	12/30/2021
5	Updated quantitative risk analysis with rebaseline risk register using @risk for VC review. V. O'Dell	3/11/2022
6	Updated quantitative risk analysis with risk register using @risk for NSF rebaselining review. V. O'Dell	4/6/2022
7	Add specific sections for discussion of partner in-kind risks, cargo sequence float management, on-ice risk management and schedule risk analysis methodology as per the recommendations from the May 2022 rebaseline review. A discussion is ongoing about which risks are owned by the project and which by NSF; this will continue to be updated as the project moves forward. Added Project Director into the responsibility matrix. Removed the details of the Monte Carlo simulation: this will go in a separate document with both budget and schedule risks. M. Duvernois, V. O'Dell	7/1/2022
8	Added more information on logistics risks, risk ownership, partner in-kind risk. Cargo sequence float management is defined and discussed. Reference to the Logistics Analysis of Alternatives. V. O'Dell	7/15/2022

1 Contents

1.1 Purpose

The purpose of this document is to define the risk management processes, based on standard best practices, that are used for the IceCube Upgrade project. This document details the responsibilities and process of the Risk Management procedures adopted by the IceCube Upgrade Project, 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).

The IceCube Upgrade Project, an upgrade to the existing IceCube Neutrino Observatory, presents unique risks associated with work at the South Pole, namely in the logistics chain to get personnel and equipment to the South Pole Station, on-ice risks where the on-ice season dates are fixed and the environment challenging, and off-ice risks which can be handled more like "routine" risks.

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 to achieve the project goals. We consider three types of risks:

- **threats** have negative impacts (the majority of entries in the Risk Register).
- **opportunities** have positive impacts (only one currently in the Registry); and
- **uncertainties** may have either negative or positive impacts (though there are none at the moment in the IceCube Risk Registry).

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. Within IceCube, we have followed reviewer advice and put in the explicit probability percentage for risk probabilities, though all the risk ranking scores and bins are still valid.

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. For the IceCube Upgrade, these key milestones are shipping deadlines to get materials into the logistics stream to be sent to the South Pole for each critical Field Season, and the Field Season dates, the approximately 15 weeks the project has during the Antarctic summer to deploy equipment and personnel. These dates form the basis of the Critical Path for the project.

Risk contingencies are determined at an **80% confidence level**, which implies that on average eight out of ten projects will be completed within cost and on schedule.

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-scope and down-scope, along with the scientific impact, is documented in the Scope Management Plan (5).

3 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 (this document). This document is part of the IceCube Quality and Safety planning process.
2. A **Risk Register** which documents the identified risks, mitigations, cost, and schedule exposures. This is reviewed at least quarterly by the L2 managers with the Quality and Safety Manager.
3. A **Quantitative Risk Analysis** to determine the risk exposure of the project, and the amount of contingency needed to control the risks. This analysis is performed on the Risk Registry using Monte Carlo tools.

4 Risk Identification

Risk identification is an ongoing process during the execution of the project. Some risks are retired while new risks may be identified. Risks are identified and analyzed through a variety of ways: brainstorming, interviews with SMEs, risk workshops involving project members and external experts, weekly technical calls, and lessons learned from the original IceCube Project (IceCube Gen1).

The process of identifying risks 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 more 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 1, which summarizes a broad range of common risk areas. This diagram is used by the project to sort risks between the different categories and to ensure all areas have been covered. CAMS and SMEs walk through this diagram to identify risks in their particular areas. After all possible risks have been documented, the project office reviews the risks for completeness and ensures all risks are synchronized. Many of the IceCube logistics-related risks are captured in External risks rather than PM risks due to the relationship between the project and the logistics stakeholders being more of collaboration and subcontractors rather than related to supply chain management.

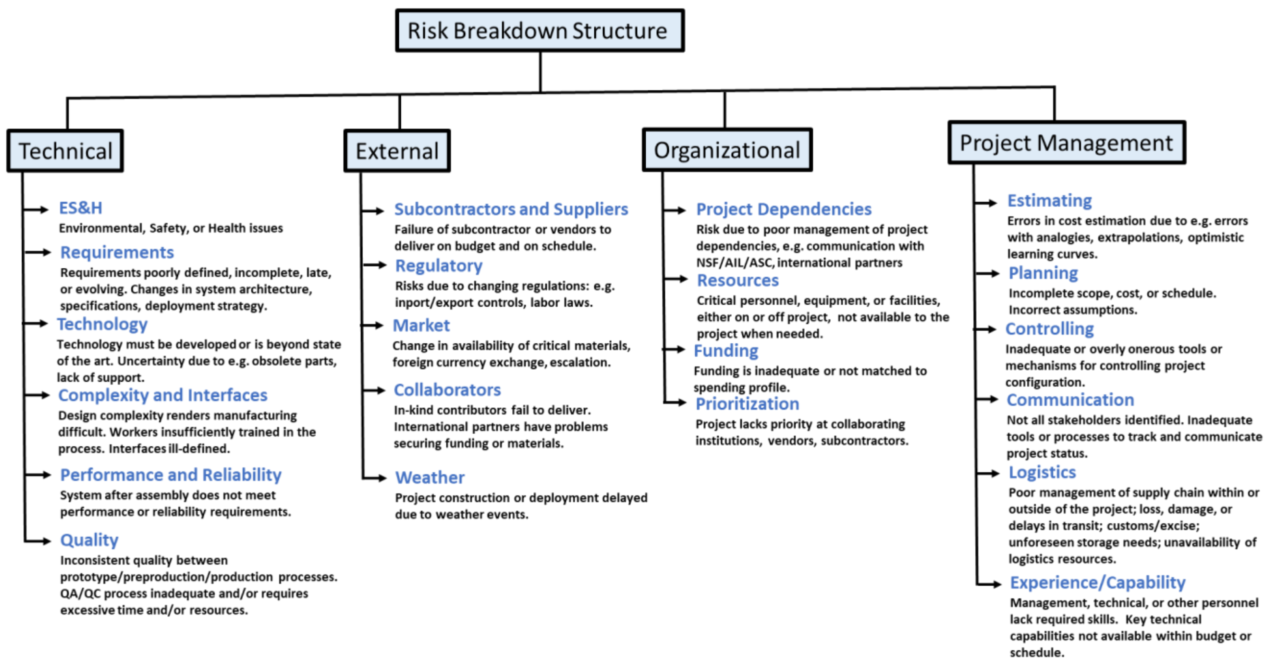

Figure 1 Risk Breakdown Structure Categories. These are broad categories to guide the Risk Identification process to ensure all risks are captured.

Risk Register

All risks identified by the Project team and stakeholders 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 of the risk

- 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)
- 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.

5 IceCube Upgrade Risks and Risk Management

The IceCube Upgrade has four broad areas of potential risks that represent risks internal to the project, risks from partners contributing to the project (in-kind), Cargo and Logistics risks, and On-Ice Risks, which are discussed in the next sections.

5.1 On-Project Risks

These are risks within the NSF scope of the project. Each is identified by the WBS entry, the risk owner (often either the WBS owner, or a higher level, perhaps L2 SME), and mitigation strategies if applicable. These risks have associated risk probabilities, assessed by the owner in concert with the project office, and cost & schedule impacts if the risk is realized. These costs are assumed to be NSF costs, which would be taken from contingency. The schedule impacts are put into the scheduling tools to evaluate the severity of their impacts to the critical path.

5.2 Partner in-kind Risks

All in-kind deliverables by IceCube Upgrade partners are defined in the Project's WBS and are elements in the Projects Integrated Master Schedule. These areas also have risks, which are outside of the NSF scope of the project. These risks are entered into the Risk Register, and each is identified by the associated WBS area, the risk owner (as above), and mitigation strategies if applicable. Each of these risks are assigned probabilities by the Subject Matter Experts. In general, these risks have only associated schedule impacts, as the cost impacts of realizing the risks are borne by the in-kind institution. The exceptions are a series of risks, one for WBS 1.3, 1.4, 1.5, and 1.6, (risks EXT21-24) which represent the loss of in-kind (contributed) labor for which the mitigating response is to use on-project funds to support replacement labor if the mitigation is not possible at the in-kind partner institution.

5.3 Cargo and logistics Management

Within the Risk Registry, we highlight the cargo and logistics risks. These are highlighted in blue in the Excel spreadsheet of the Risk Registry and have assigned risk probabilities (in many cases determined in coordination with the logistics managers at NSF and/or ASC), as well as cost and schedule impacts. The on-project cost and schedule impacts are shown in the registry and included in the quantitative risk analysis.

Cargo can be transported in several different ways in the USAP cargo stream once delivered to either Port Hueneme or Christchurch entry sites. These pathways are detailed in the Key Assumptions Document(6).

In order to ensure that South Pole cargo arrives prior to the time needed for on-ice tasking, the Project Office, and especially the Logistics Manager, monitors ready-to-ship and shipping dates in the Master Schedule. Project cargo "ready-to-ship" dates are updated monthly during the monthly schedule updates by the CAMs; these dates are propagated into the "Master Cargo Spreadsheet" which is used to communicate with the Antarctic Contractor's Transportation and Logistics (T&L) section and the science support project manager

Note that the Master Cargo Spreadsheet contains much more than just the shipping dates, but also provides additional information including shipment dimensions, weight, cargo characteristics (i.e. Do Not Freeze, Do Not Deep Freeze & Hazardous), ready-to-ship date, origin/owner, shipping path, and Required-on-Site (ROS) dates. This additional information is critical to communicating and planning on-schedule cargo arrival with the USAP; i.e. space on missions, traverse (SPOT) sleds, DNF, and/or DNDF storage capacity and that the planned ROS meshes with the Project's need.

Cargo sequence float management (that is, managing the float related to each item in the cargo list, and the method by which that cargo is delivered to the South Pole) is ultimately the responsibility of the Project Manager, who uses the information from the updated Integrated Master Schedule, in consultation and concurrence with the Logistics Manager, to ensure cargo enters the cargo stream in a timely fashion. The Logistics Manager takes responsibility for communicating all cargo needs to USAP. All cargo floats are reported monthly; any cargo with less than 90 days of float, from the "ready-to-ship" date to the "must-ship-by" date is identified by the Logistics Manager and brought to the attention of the Project Office. Situation Reports (SitReps) are required biweekly from areas with cargo floats less than 90 days, weekly for cargo floats less than 60 days, and daily for cargo floats less than 30 days.

5.4 On-Ice Risks

In the risks from WBS 1.2 (Drill and Installation), the risks specific to the on-ice Field Seasons are separated out. These risks are a mix of internal (to the project) risks and external ones. They are separated from the Off-Ice risks to enable an easier analysis of the scheduling risks; Off-Ice tasks typically culminate in shipping dates, passing materials and personnel to the NSF/ASC risks, and then the On-Ice risks manifest during the field seasons at South Pole which are strictly delineated by the South Pole season and availability of space at South Pole. These risks additionally have few mitigations available outside of personnel, equipment, and contingency plans at the Pole.

6 Risk Ownership

The IceCube Upgrade project is responsible for building the detector elements, the enhanced hot water drill (EHWD), the supporting infrastructure hardware, and ensuring all the parts get into the logistics stream in proper time to be used for the appropriate Field Season. The Project is also responsible for identifying, training, and physically qualifying (PQ) all needed personnel needed for the South Pole effort.

All risks on the hardware, firmware, and software of the detector components, their infrastructure elements in the ice and inside the IceCube Laboratory, the safety of personnel working on the drilling and installation, and the performance of all the equipment built by, or used by, the project team are held by the project. Commercial shipping, inflation, personnel departures, and supply chain risks for required components are all project-held risks called out in the Risk Registry.

Additional risks have been identified by the project that are external to these areas: for example, risks in delays once items are in the logistics chain, risks that USAP does not deliver the efforts requested and negotiated by the Project, or risks of specific logistics capacities negotiated and agreed which are not available. The Project has made a best effort to identify and quantify these risks. These external risks that impact the Project are also in the Risk Register, and are considered when understanding overall contingency needs for the project. All risks in the Risk Register are considered "on project" risks, and are monitored and mitigated by the Project. An example of a risk that is external to the Project, but for which the Project is taking steps to mitigate, is the risk of flying missions to the South Pole to deliver the fuel that the Project needs to run the Enhanced Hot Water Drill. In this particular case, the probabilities of completed flights was analyzed using information provided by NSF – AIL, and it was determined that buying tanks to move the fuel would mitigate the risk substantially, and the Project is using contingency funds to do so, while USAP is ensuring that the tanks get delivered to McMurdo for use on overland transport. For more details on this example see (7).

More catastrophic risks, such as external factors cancelling a Field Season (such as new pandemic risks or other global crises that limit access to the South Pole) are not considered in the Risk Register. These catastrophic risks, while low in probability, would necessitate a new baseline for the Project.

7 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 members of the Project Office, 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 Director (PD)

- 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
- Reports on risks to oversight bodies

Project Manager (PM)

- Implements the project's risk processes and systems
- Coordinates with the project team, the technical coordinator, and the quality manager to hold regular risk workshops
- Assigns a **Risk Owner** to each risk (see below)

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 and mitigation 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. (This role is temporarily filled by the PD until the Project Controls team is firmly onboard).

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. In many cases this is the cognizant L2, or in some cases, a L3 SME.

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, PD, 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, while 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 Director	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	-	Contributes	Reviews
Identify Risks	Accountable	Contributes	Contributes	Contributes	Contributes	-	Contributes	Reviews
Perform Qualitative Risk Analysis	Accountable	Contributes	Contributes	Contributes	Contributes	-	Performs	Reviews
Perform Quantitative Risk Analysis	Accountable	Contributes	Contributes	Contributes	Contributes	Performs	Contributes	Reviews
Plan Risk Responses	Accountable	Contributes	Contributes	Contributes	Performs	-	Performs	Reviews
Monitor and Control Risks	Accountable	Contributes	Performs	Performs	Performs	-	Performs	Reviews

Table 1 Risk Responsibility Matrix for the IceCube Upgrade Project.

8 Qualitative Risk Analysis

The qualitative risk documents 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 2.

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.

Risk Ranking

A matrix of risk probability vs. impacts, shown in Figure 2, is used to rank the risks. Figure 3 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. As it was recommended by reviewers, and does help especially with very low probability risks, we have refined this with risk percentages called out numerically, but all bin information is also kept.

	Impact Level				
Probability	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 2 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	Minor areas of scope affected	Major areas of scope affected	Scope reduction	Project item is

	barely noticeable			unacceptable to sponsor	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 3 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. For example, EXT18 (mDOM electronics parts availability problems) is a high ranked risk, with large schedule delay possibilities and a high risk of occurrence.
- **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. For example, PM2 (Inflation in personnel salaries) is a moderate rank risk with both schedule and cost impacts judged to be moderate.
- **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. Among many examples, TECH30 (Dust logger winch failure) is relatively unlikely to take place, can be mitigated in situ, and has small impacts in the cost, schedule, and technical performance.

The project flags risks in the high and moderate risks as "Major Project Risks" which stand out above a larger number of Low Rank risks, many of which have quite low-cost impacts. 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 substantially increase in the future.

9 Quantitative Risk Analysis

9.1 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 taken from the Risk

Register, and the risk cost impact is a PERT function with minimum, maximum, and most likely values taken from the risk register.

Risks may also have a schedule impact as detailed in the Risk Register. All schedule risks in the Risk Register have been implemented as probabilistic duration delays in a simplified schedule of the critical path, and @risk was used to calculate these probabilistic delays. Again, the risk schedule impact was implemented as a PERT function with minimum, maximum, and most likely values taken from the risk register.

The total cost of the risk events come both from the MC of the cost impact as well as the MC for the schedule impact, where labor may continue to be expended as the schedule expands. The risk Monte Carlo analysis, for both cost and schedule impacts, is described in (6).

10 Monitoring Risks

High- and medium-rank risks are monitored by the Project and documented in the Project monthly reports to the NSF. These are flagged with the “Major Risk Flag” in the Risk Registry. Risk workshops are held at least quarterly to monitor current risks and ensure that all risks are captured. Any additional risks identified during these workshops are promptly assessed for their impact on the project budget and schedule.

The Project Director, 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.

Within the project, any request to use contingency funds must be documented in a Change Request document and approved by the National Science Foundation Program Officers according to the contingency usage thresholds specified in the IceCube Upgrade Project Execution Plan (7).

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.

11 Bibliography

1. **U.S. Government Accountability Office.** *Cost Estimate and Assessment Guide: Best Practices for Developing and Managing Program Costs.* 2020.
2. **National Science Foundation.** *Research Infrastructure Guide.* 2021.
3. **Project Management Institute.** *A Guide to the Project Management Body of Knowledge (PMBOK Guide).* 6th Edition. 2017. ANSI/PMI 99-001-2017.
4. **IceCube Upgrade Project.** *Risk Register.*
5. —. *Scope Management Plan.*
6. —. *Key Assumptions for the IceCube Upgrade Project.* 2022.
7. —. *IceCube Upgrade Logistics - Analysis of Alternatives.* 2022.
8. —. *Monte Carlo Treatment of Discrete Risks for the IceCube Upgrade.*
9. —. *The IceCube Upgrade Project Execution Plan.*
10. **National Science Foundation.** *Major Facilities Guide.* 2019.