# Risk Schedule and Budget Assessment

**2022-009.1.2**

## Approval / Date

| | Approval | Date |
|---|---|---|
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## Change Log

| Revision | Description: Author | Date |
|---|---|---|
| 1.0 | Original Document. Contains the MC analysis of the risk register for both cost and schedule. Originally only direct cost impact was done, and it was in the Risk Management Plan. V. O'Dell | 7/10/2022 |
| 1.1 | Fixed "purpose" section. V. O'Dell | 7/11/2022 |
| 1.2 | Incorporated comments from NSF. Added 70% confidence level (as the RIG specifies 70-90% as a range of CL's for risk analyses). Also added more detail on how the schedule risk MC is done. Updated analysis to align with most recent Risk Register. | 7/22/2022 |

## Contents

## 1. Purpose

The purpose of this document is to quantify the risks to both budget and schedule for the IceCube Upgrade Project. The IceCube Upgrade Project was started in October 2018 as a 5 year project, however serious impacts from the COVID pandemic has led to delays in the Project, both internally and externally, necessitating a comprehensive look at the needs of the project in terms of cost and schedule in order to ensure success. This will require a new baseline for the project, which includes recent input in logistics capabilities from the NSF. The logistics capabilities are sufficient to support the necessary three Field Seasons (FS1, FS2, FS3) in FY24-FY26, with the FS3 being the main drill season for the project. With these logistics assumptions, and better understanding of the project timeline, the Project's Risk Register was revisited to ensure all risks are captured. This document describes the effects of all Project risks on the cost and schedule of the rebaselined project.

## 2. Introduction

The risk management processes are described in the *IceCube Upgrade Risk Management Plan* (1). The output of these processes is summarized in the *IceCube Risk Register* (2). The risk register contains a risk ID, a post-mitigated risk impact assessment on cost, schedule, and technical scope or quality, and a post-mitigated risk probability of occurrence. The risk register is a "living document" in that risks are retired, their probabilities or impacts may change over time, and new risks may be added during the course of the Project. The impact of the risks in the risk register is recalculated whenever the register is updated.

The aggregate impacts of risks are assessed, using a Monte Carlo (MC) model based on the resource-loaded schedule (RLS) and risk register. The cost impacts of residual risks, after mitigation, 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. In the case of the IceCube Upgrade, the risk-based contingency consists of estimate uncertainties for each activity in the schedule, and discrete risk events that are captured in the risk register. The total budget contingency is the sum of the estimate uncertainties and the discrete risk impacts from the risk register.

The NSF *Research Infrastructure Guide* (3) specifies that the risk confidence level should be taken between 70-90%. For the IceCube Upgrade Project, risk contingencies are determined at the **80% confidence level**, which implies that on average eight out of ten projects will be completed within cost and on schedule. The analysis below gives the budget and schedule contingency for 70%, 80%, and 90% for completeness.

Risks in the risk register contain both cost and schedule risks for discrete risk events. For both cost and schedule, the risk register contains the maximum cost and schedule impacts, the minimum cost and schedule impacts, and the most likely cost and schedule impacts. In the sections below, we discuss how these impacts and probabilities are used to calculate the overall cost and schedule contingencies.

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## 3. Schedule Risk analysis

As described above, the minimum, most likely, and maximum value for the schedule impact is detailed in the risk register. In order to calculate the impact on the schedule that the risk has, we do the following:

1. Identify the Critical Path leading up to major milestones
2. Identify the activities on the Critical Path that are impacted by risk events
3. Allow these activities to move, and thus push out the milestones according to a probabilistic calculation of the schedule impacts for the risk event

The sections below describe each of these steps in detail. An important note is that the schedule has some hard constraints, namely:

- Shipping dates – details of how components get shipped to the South Pole are described in the Key Assumptions Document and the Logistics Planning Document. The shipping dates for particular modes of transportation are inflexible; however the project may have some flexibility in which mode of transport to use. All logistics details (such as volume, weight, method of shipping, date "Required on Site", etc.) are captured in the Cargo Master Spreadsheet and communicated well in advance with the US Antarctic Program to ensure there is a suitable method of transport for each item.
- Field Season dates – the Field Seasons occur during the Antarctic summer and are defined in advance. In general they run from early/mid-November to mid-February.

For the schedule risk analysis described below, shipping dates were allowed to float, and the (risk adjusted) available shipping time is shown in the schedule. The available shipping time is defined by the difference between the "Required on Site" date and the "Ready to Ship" date.

For the Field Seasons, the start of the field season is fixed, and the duration of the field season is allowed to float.

Note that the project's critical path runs through the Field Seasons. After FS3, the off-ice work consists of finalizing the initial calibration constants before handing the new detector off to the ongoing Maintenance and Operations of the IceCube Neutrino Observatory. There are no schedule risks associated with this final block of work. There is a risk, documented in the risk register and included in the Monte Carlo analysis, that captures the small (1%) probability of the project needing a fourth Field Season to complete. This risk also captures the cost of extending the project office for an additional year. This risk would only be realized after all descoping options are exercised (4) which is why it is considered very unlikely.

### 3.1. Identify the Critical Path leading up to major milestones

The critical path has been identified in the resource loaded schedule by reviewing all activities leading up to the set of major milestones in Table 1 and Table 2. The Upgrade Project is a simple project: effectively it is dominated by shipping the instrumentation and drill refurbishment parts to the South Pole, and on-ice tasking over three field seasons to complete and commission the drill, accept and test the instrumentation, and drill and deploy the detector.

### 3.2. Identify the activities on the Critical Path that are impacted by risk events

Each activity whose schedule could be impacted by risk events was identified in the schedule, and additional "risk tasks" or "risk hooks" with a probabilistic duration was inserted to represent the risk being realized. This risk duration was then allowed to push out the scheduled tasks with a duration and probability that is documented in the risk register.

### 3.3. Allow activities to move according a probabilitistic calculation of the schedule impacts

The input schedule risk durations are modeled as a PERT distribution with a minimum, most likely, and maximum value, as documented in the risk register. As an example, Figure *1* (left) shows the PERT schedule distribution (in weeks) for risk Tech34 (D-Egg FAT Yield), which is the risk that the Final Acceptance Testing of the D-Egg optical modules discovers problems that require substantial rework of the modules. The PERT distribution shows a smooth distribution between the minimum (12 weeks) and maximum (52 weeks), peaking at the most likely value (26 weeks). This is the input distribution used for this particular risk. The probability of the risk to be realized is estimated at 5%. The Monte Carlo program (@risk) then performs 100k simulations, choosing at random a duration input from the PERT distribution each time the event is projected to occur probabilistically in order to arrive at a distribution of outcomes. Figure 1(b) shows the output distribution for this one particular risk. This duration in weeks is then used as the duration of the "risk task" and is allowed to push out the schedule for the completion of the full D-Egg Final Acceptance Test, and all downstream tasks (i.e. packing, and shipping of the D-Eggs)

(As an aside, the FAT is ongoing at the time of this writing and has not yet turned up any issues. This risk will likely be retired, or reduced, in the next several months). Probabilities in the risk register are estimated by SME's and are definite numbers (not binned ranges).

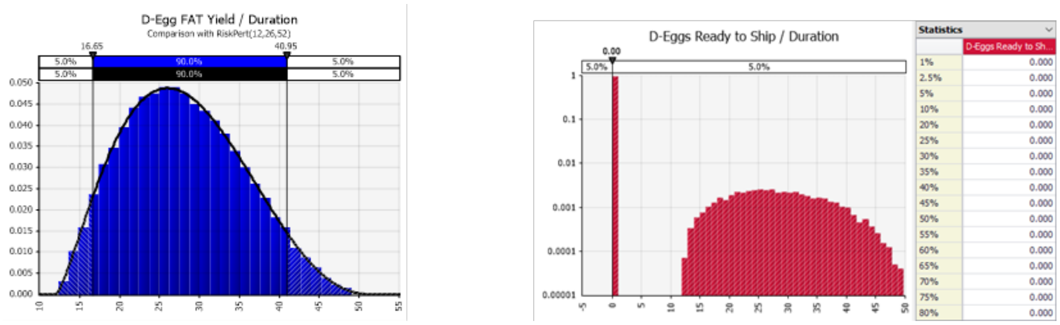


*Figure 1 (a): PERT input distribution of schedule impacts for the D-Egg FAT testing risk (Tech34), (b): probability*impact distribution of Tech34. Note that the figure on the right is on a log scale.*

The essential schedule elements, defining the critical path, are shown as the blue bars in Figure 2. This is a simplified schedule from the IceCube Integrated Master Schedule in SmartSheets. The risk adjusted results, at 80% CL,  are shown as the orange bars in the figure. For items needing to enter the logistics stream, the green bars show the available shipping time (difference between Required on Site and item Ready to Ship) for the baseline and the brown bars show the available shipping time after adjusting for the risks.

The bottom three bars represent the Field Seasons. The start of the Field Seasons is fixed and the end date is allowed to fluctuate with the probabilistic duration of risk events during each Field Season. Because the final Field Season (FS3) is critical to the success of the project, and carries the most risk, additional detail for FS3 is shown in Figure 3. Figure 3 also shows the end dates for completing 5 strings or 7 strings (options described in the scoping document).

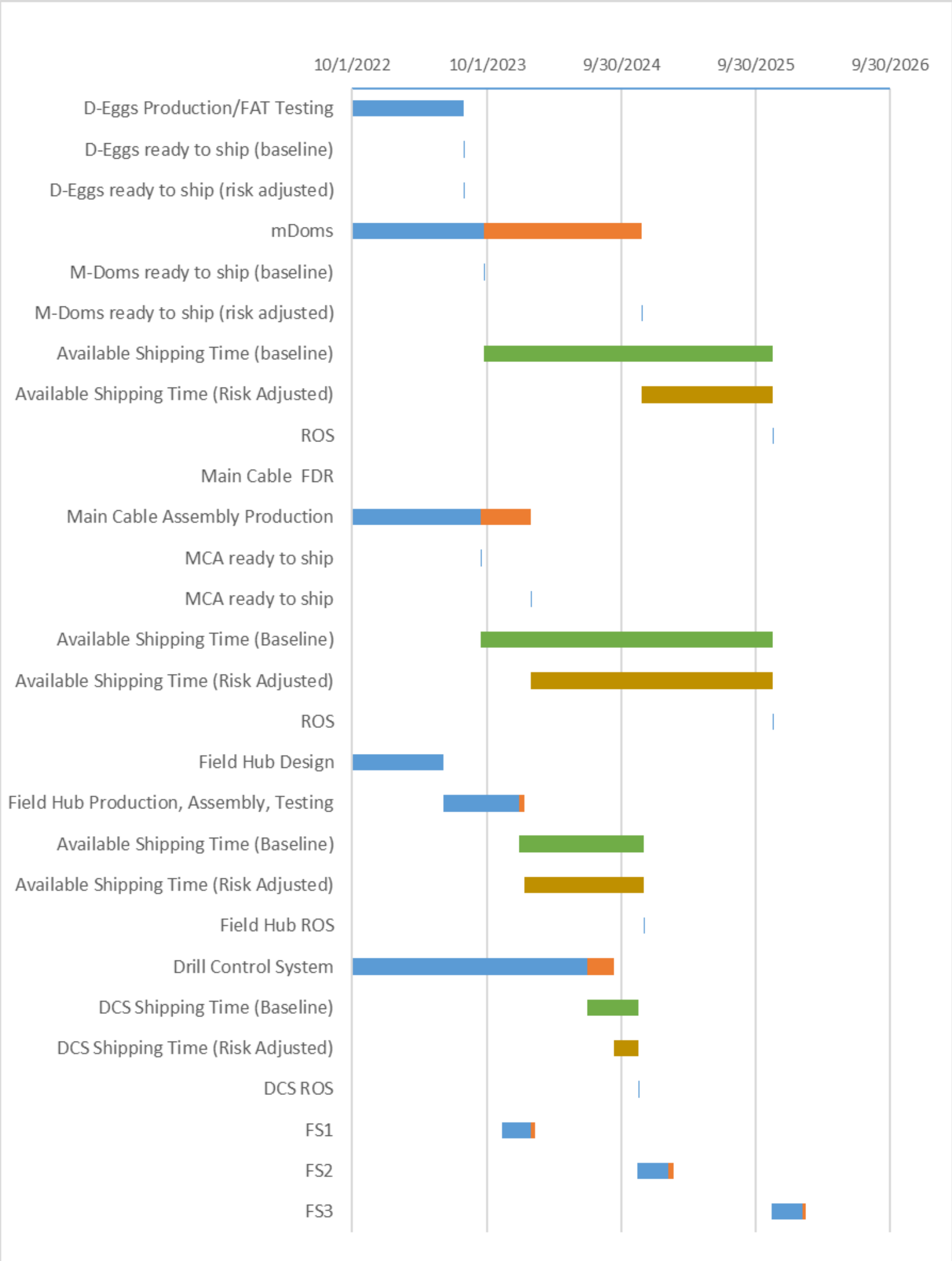


*Figure 2 Overall schedule of the IceCube Upgrade showing the critical elements that may be impacted by risks. The blue bars are the baseline task dates and durations, and the orange bars are the risk adjusted task end dates. The green bars show the available shipping time (difference between Required on Site and item Ready to Ship) for the baseline and the brown bars show the available shipping time after adjusting for the risks.*

Additional information, including baseline dates, risk adjusted dates (70%, 80%, and 90% CL) Table 1. We note that the risk adjusted dates for FS1 and FS2 are slightly beyond the normal end of season at the South Pole (nominally ~ Feb. 9 or so), but we believe we can further refine the schedule to reduce the time needed to complete the tasking.

For the Drill Control System, parts will be shipped both for FS1 and FS2. The dates in the schedule show the latest dates for parts being shipped in FS2. The DCS is planned to be shipped commercial surface directly to NZ for transport to the South Pole, hence the shipping windows are much smaller, however, the risk analysis clearly shows that the schedule as it is currently envisaged is very tight and must be accelerated.

| IceCube Upgrade Project Overview | | | | | |
|---|---|---|---|---|---|
| Task | Baseline Start | Baseline Finish | Risk Adjusted Finish (70% CL) | Risk Adjusted Finish (80% CL) | Risk Adjusted Finish (90% CL) |
| D-Eggs Production/FAT Testing | 5/1/2022 | 7/31/2023 | 7/31/2023 | 7/31/2023 | 7/31/2023 |
| mDom Production Complete | 5/1/2022 | 9/23/2023 | 10/25/2024 | 11/20/2024 | 12/23/2024 |
| Main Cable Assembly Production | 8/31/2022 | 9/14/2023 | 11/24/2023 | 2/1/2024 | 4/21/2024 |
| Field Hub Design | 1/1/2021 | 6/5/2023 | 6/5/2023 | 6/5/2023 | 6/5/2023 |
| Field Hub Production, Assembly, Testing | 6/5/2023 | 12/26/2023 | 12/30/2024 | 1/12/2024 | 2/10/2024 |
| Drill Control System | 5/2/2022 | 7/1/2024 | 8/30/2024 | 9/8/2024 | 9/18/2024 |
| Field Season 1 | 11/12/2023 | 1/29/2024 | 2/10/2024 | 2/14/2024 | 2/18/2024 |
| Field Season 2 | 11/12/2023 | 2/4/2025 | 2/11/2025 | 2/12/2025 | 2/15/2025 |

*Table 1 Baseline and Risk Adjusted dates for items on the critical path.*

Field Season 3 is the critical drilling season, that also carries the most risk. In this case we broke down the tasking a bit further to study the effect of risks on the task durations.

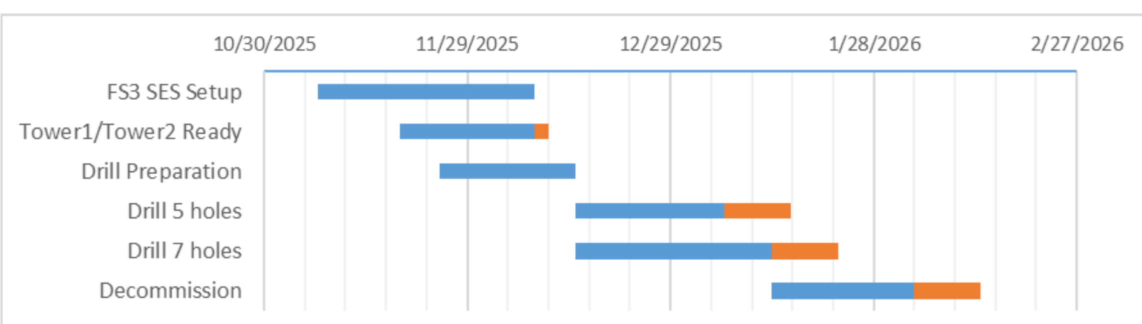

*Figure 3 More detail on FS3, which is the critical Field Season for the project and carries the most risk.*

Additional information, including baseline dates, risk adjusted dates at 80% CL and 90% CL for Field Season 3 is shown in Table 2. Note that the Decommission task allows for 21 days to pack equipment for retrograde – we believe this can be compacted considerably, which allows us to complete all 7 holes within the allotted field season at a high confidence level.

| Field Season 3 Overview | | | | | |
|---|---|---|---|---|---|
| Task | Baseline Start | Baseline Finish | Risk Adjusted Finish (70% CL) | Risk Adjusted Finish (80% CL) | Risk Adjusted Finish (90% CL) |
| FS3 SES Setup* | 11/7/2025 | 12/9/2025 | 12/9/2025 | 12/9/2025 | 12/9/2025 |
| Tower1/Tower2 Ready | 11/19/2025 | 12/11/2025 | 12/11/2025 | 12/11/2025 | 12/11/2025 |
| Drill Preparation | 11/25/2025 | 12/15/2025 | 12/15/2025 | 12/15/2025 | 12/18/2025 |
| Drill 5 holes | 12/15/2025 | 1/6/2026 | 1/13/2026 | 1/16/2026 | 1/23/2026 |
| Drill 7 holes | 12/15/2025 | 1/13/2026 | 1/20/2026 | 1/23/2026 | 1/30/2026 |
| Decommission ** | 1/13/2026 | 2/3/2026 | 2/10/2026 | 2/12/2026 | 2/20/2026 |

*Table 2 Breakdown of major tasks during Field Season 3, the baseline start, baseline end, and risk adjusted end both at 80% and 90%. Note that the FS3 SES Setup (*) is started by USAP before the IceCube deployment team arrives (nominally Nov. 15). At the end of the drilling, 21 days are allocated for decommissioning and packing up for retro. The final risk adjusted dates in the table add this decommissioning time to the risk adjusted dates for drilling 7 holes.*

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### 3.4. Analysis of Schedule Contingency

Schedule contingency is held at the end of the project. The relevant milestones for the end of the project are given in Table 3. Approximately 2 months are allotted for the Project Closeout, which includes writing the final report and collecting and finalizing the financial reports for the project. Of note is that the difference between the baseline finish and the 90% confidence level finish is only ten days. This is driven by the deployment of the detector during FS3. Because the Field Seasons are heavily constrained, the project end date is not expected to shift: instead descoping options would be initiated in order to finish the Field Seasons on time.

| Major Milestones | | | | | |
|---|---|---|---|---|---|
| Task | Baseline Start | Baseline Finish | Risk Adjusted Finish (70% CL) | Risk Adjusted Finish (80% CL) | Risk Adjusted Finish (90% CL) |
| Field Season 3 | 11/7/2025 | 2/3/2026 | 2/10/2026 | 2/12/2026 | 2/20/2026 |
| Commission devices following deployment | 12/18/2025 | 3/31/2026 | 3/31/2026 | 4/2/2026 | 4/10/2026 |
| Handoff to M&O | 4/7/2026 | 4/7/2026 | 4/7/2026 | 4/9/2026 | 4/17/2026 |
| Project Closeout | 4/7/2026 | 6/2/2026 | 6/2/2026 | 6/4/2026 | 6/12/2026 |

*Table 3 Major Milestones marking the end of the Project.*

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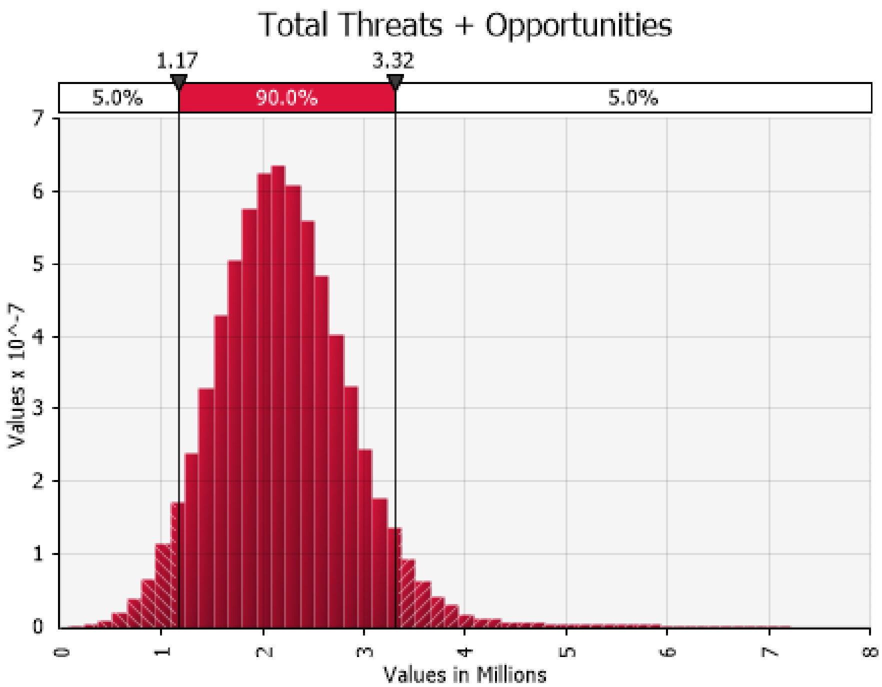
## 4. Cost Risk analysis

Risks in the risk register also have cost impacts, which are also modeled as PERT distributions using the low, most likely, and high elements in the cost impact of the risk register. This analysis is used to determine the "risk-based contingency" budget, at a high confidence level. The "risk-based contingency" is distinct from the "cost estimate uncertainty contingency", which covers the uncertainties in labor and equipment estimates, according to the maturity of the design and/or estimate.

The overall discrete risk-based contingency is calculated using the @risk program, with 100k iterations of possible outcomes. The results are shown in Figure 1 and tabulated in Table 1.




| Statistics | Total Threats + Op... |
|---|---|
| 5% | 1,174,881.02 |
| 10% | 1,390,154.56 |
| 20% | 1,650,640.92 |
| 25% | 1,753,944.51 |
| 30% | 1,843,837.98 |
| 35% | 1,930,039.56 |
| 40% | 2,012,614.88 |
| 45% | 2,091,325.27 |
| 50% | 2,168,687.73 |
| 55% | 2,248,855.42 |
| 60% | 2,331,589.68 |
| 65% | 2,416,052.19 |
| 70% | 2,505,992.01 |
| 75% | 2,605,365.27 |
| 80% | 2,720,820.97 |
| 90% | 3,029,680.49 |
| 95% | 3,316,217.10 |

*Figure 4 Total cost of discrete risks (both threats and opportunities) as calculated from the entries in the IceCube Upgrae Risk Register. This plot shows the results of 100k simulations of possible risk outcomes.*

| Results of Cost Impact from ***Discrete*** Risks | |
|---|---|
| Confidence Level | Risk Cost Impact |
| Total at 70% CL | $2,505,992 |
| Total at 80% CL | $2,720,821 |
| Total at 90% CL | $3,029,680 |

*Table 4 Results of the @risk monte carlo analysis of cost impacts from discrete risks. IceCube Upgrade uses the 80% confidence level in calculating the total discrete risk budget.*

Figure 5 shows the risks ranked by effect on the output mean (*i.e.*, the “tornado” plot). Details on the risks and how they were estimated are captured in the risk register.

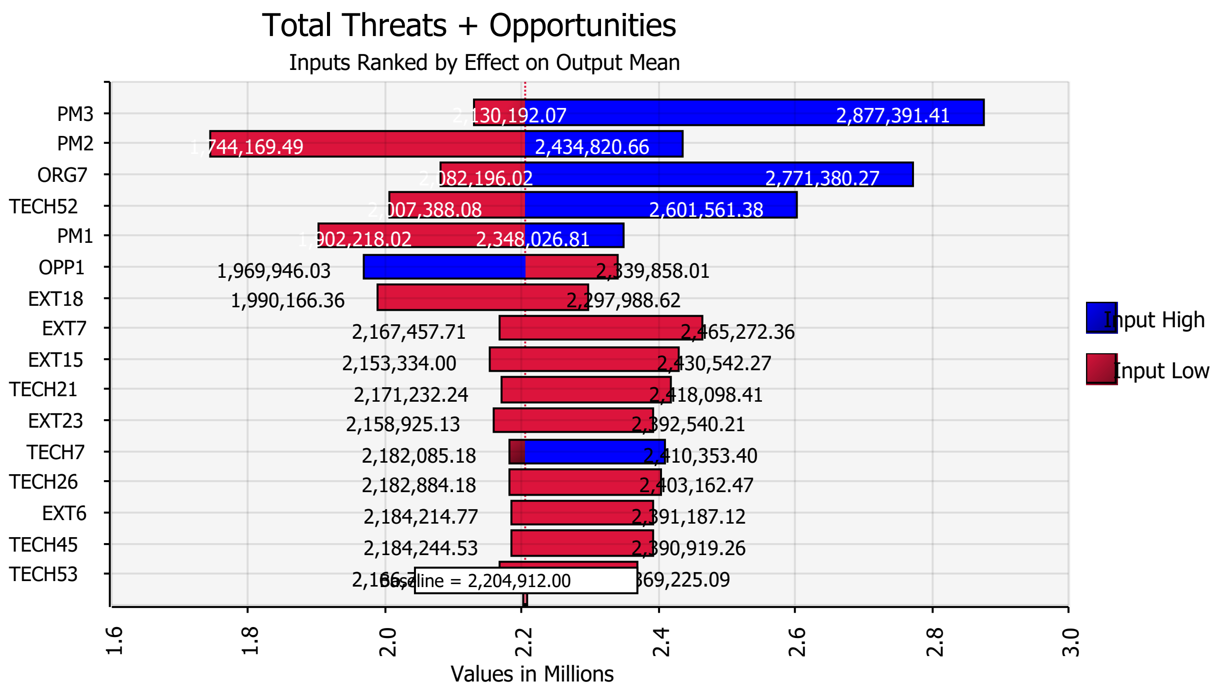



*Figure 5 Top risks in terms of cost impact. For more information on the risks and how they were estimated, see the risk register.*

## 5. Additional Cost Impacts

In addition to explicit costs from the Risk Register cost impacts, implicit costs from the adjusted schedule dates may be incurred. This would cover any "standing army" effects, for example. The explicit costs of *e.g.*, a board redesign is included in the Risk Register and covered in the cost risk analysis. In analyzing the schedule dilation due to risks, in general there is very little standing army effect. This is because, by definition, the Project must complete deployment during FS3, which has rigidly defined dates. Additional activities past deployment include calibration tasks which carry very little cost or risk.

The major schedule delays due to risks are in the mDOM Mainboard production (due to supply chain issues), which are largely carried by in-kind contributions; the main cable assembly production which is overseen by an engineer that is committed fully to and funded by the project, and the Drill Control System, which is under development by a team of engineers at UW-PSL, that are matrixed on other projects as well. The costs to these delays do not imply any "standing army" costs and are fully captured in the risk register.

The largest impact in implicit cost due to schedule risks would be the cost of an additional Field Season. This cost and probability are captured in the Risk Register, as well as the cost for extending the Project Office for an additional year. As all instrumentation and engineering would be completed, additional costs in other WBS areas are negligible. (*i.e.*, the cost of extending a postdoc or graduate student for an additional year).

## 6. Overall Budget Contingency

The overall budget contingency for the IceCube Upgrade is the sum of the cost impacts of the discrete risks (as above) and an "estimate uncertainty" cost which quantifies the impact of the uncertainty in the estimate for the project. The estimate uncertainty is assigned at activity level following guidance in the Project's Key Assumptions Document (5). The overall contingency from this source is $2,041k therefore the overall budget contingency ("estimate uncertainty" plus "discrete risks") is $2,041 + $2,721 (80% CL) = $4,762 whih 28.5% overall contingency for PY5-PY8.