Risk Schedule and Budget Assessment

2022-009.1.1

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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

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 [citation].* 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. 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 **80% confidence level**, which implies that on average eight 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.
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3. Schedule Risk analysis

Risks in the risk register contain both cost and schedule risks. The input schedule risks are modeled as a PERT distribution with a minimum, most likely, and maximum value. *Figure 1* 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. This risk is currently assigned a 5% probability, with a schedule impact between 12-52 weeks, with 26 weeks being the most likely value. (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). The Monte Carlo program then performs 100k simulations, choosing at random an input from the PERT distribution each time the event occurs probabilistically in order to arrive at a distribution of outcomes. Figure 1(b) shows the output distribution for this one particular risk by itself.

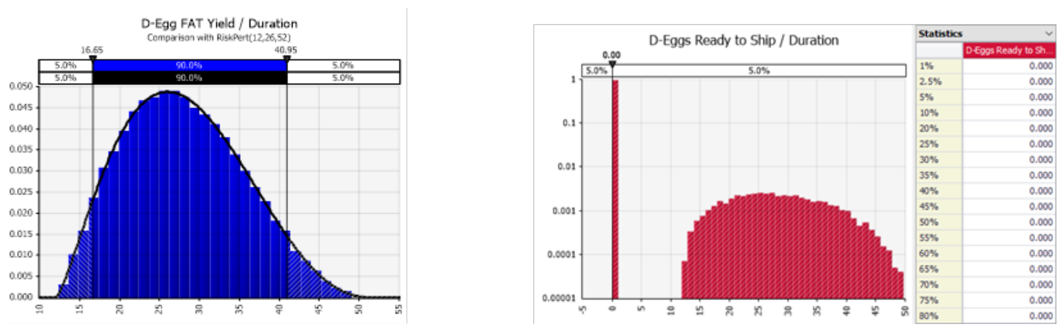


*Figure 1 (a): PERT input distribution of schedule impacts for the D-Egg FAT testing risk (Tech34), (b): probability*impact distribution of Tech34. Note that the figure on the right is on a log scale.*

The essential schedule elements, defining the critical path, is shown as the blue bars in Figure 2. This is a simplified schedule from the IceCube Integrated Master Schedule in SmartSheets. The risks from the risk register were then entered as events in the schedule and the probabilistic duration of the risks were allowed to move the schedule. The risk adjusted results, at 80% CL, are shown as the orange bars in the figure. 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.

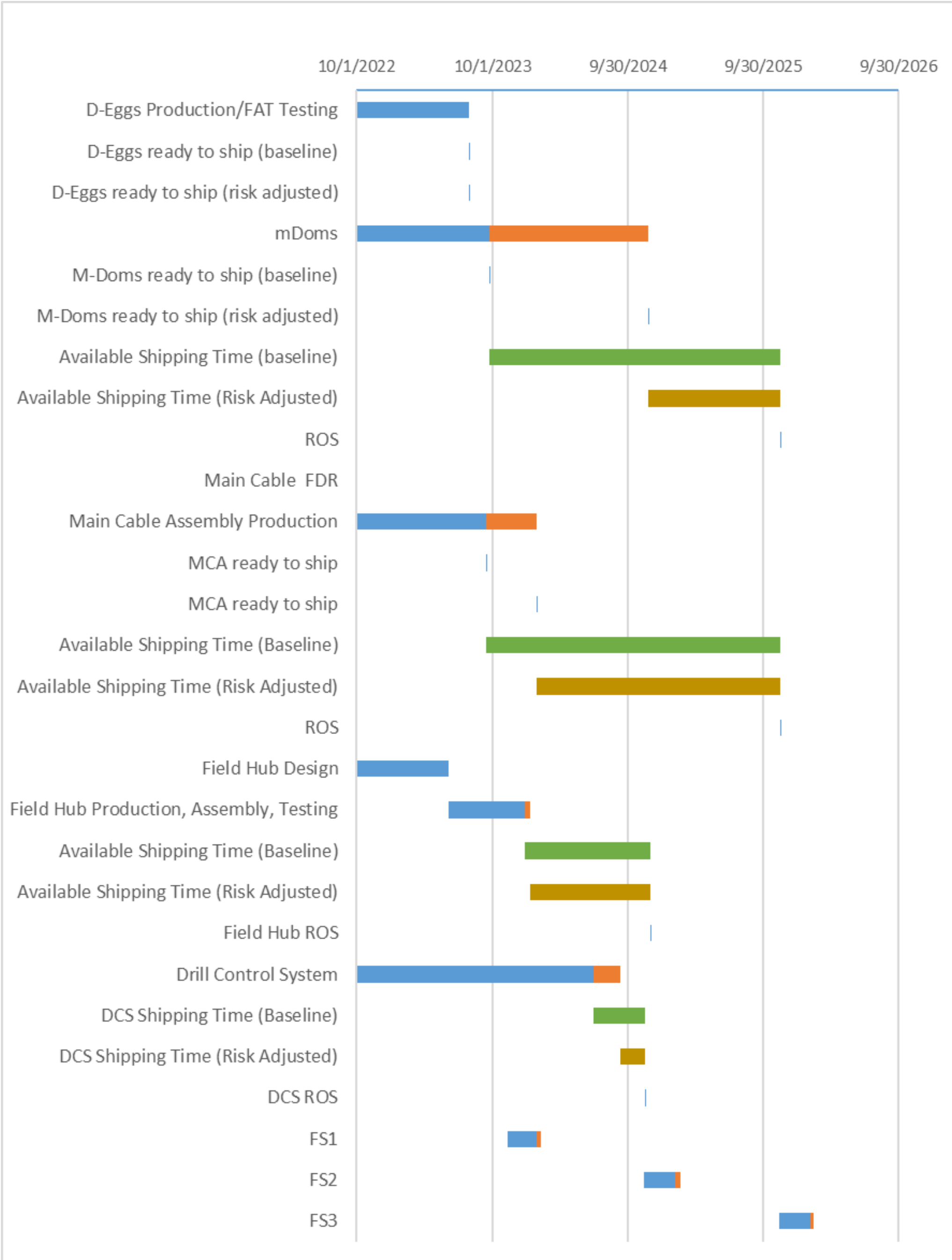


Figure 2 Overall schedule of the IceCube Upgrade showing the critical elements that may be impacted by risks. The blue bars are the baseline task dates and durations, and the orange bars are the risk adjusted task end dates The green bars show the available shipping time (difference between Required 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 (80% CL) and risk adjusted dates (90% CL) are shown in Table 1. We note that the risk adjusted dates for 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 End	Risk Adjusted End (80% CL)	Risk Adjusted End (90% CL)
D-Eggs Production/FAT Testing	5/1/2022	7/31/2023	7/31/2023	7/31/2023
mDom Production Complete	5/1/2022	9/23/2023	11/20/2024	12/23/2024
Main Cable Assembly Production	8/31/2022	9/14/2023	1/28/2024	4/17/2024
Field Hub Design	1/1/2021	6/5/2023	6/5/2023	6/5/2023
Field Hub Production, Assembly, Testing	6/5/2023	12/26/2023	1/12/2024	2/10/2024
Drill Control System	5/2/2022	7/1/2024	9/8/2024	9/16/2024
Field Season 1	11/12/2023	1/29/2024	2/14/2024	2/18/2024
Field Season 2	11/12/2023	2/4/2025	2/12/2025	2/14/2025

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.

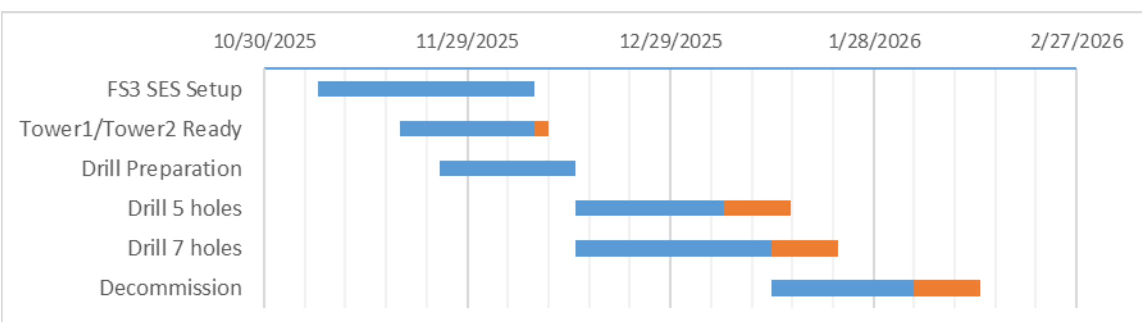


Figure 3More detail on FS3, which is the critical Field Season for the project and carries the most risk.

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.

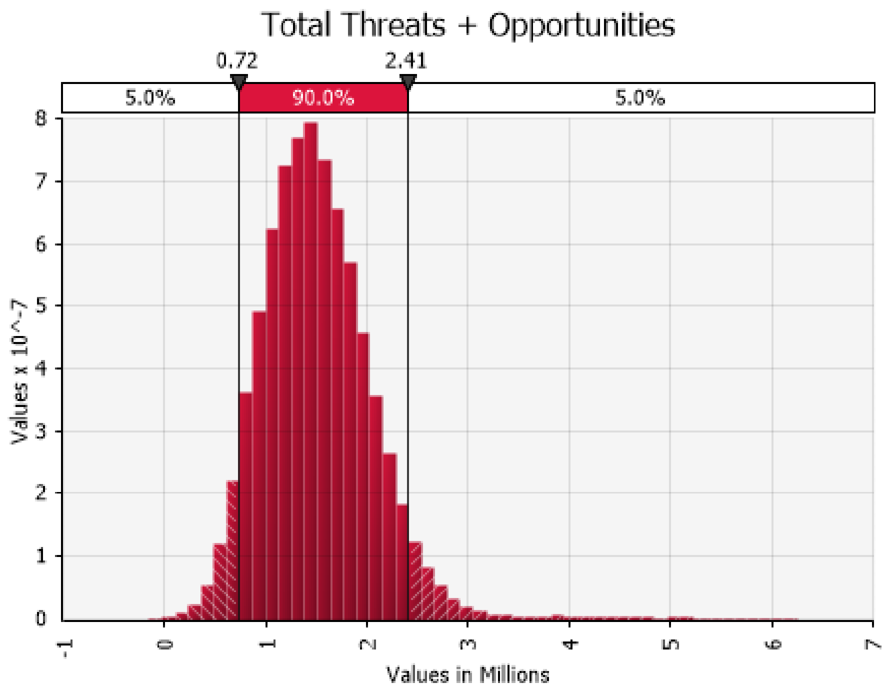
Field Season 3 Overview				
Task	Baseline Start	Baseline End	Risk Adjusted End (80% CL)	Risk Adjusted End (90% CL)
FS3 SES Setup*	11/7/2025	12/9/2025	12/9/2025	12/9/2025
Tower1/Tower2 Ready	11/19/2025	12/11/2025	12/11/2025	12/11/2025
Drill Preparation	11/25/2025	12/15/2025	12/15/2025	12/18/2025
Drill 5 holes	12/15/2025	1/6/2026	1/15/2026	1/23/2026
Drill 7 holes	12/15/2025	1/13/2026	1/22/2026	1/30/2026
Decommission **	1/13/2026	2/3/2026	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.

4. Cost Risk analysis

Risks in the risk register also have cost impacts, which are modeled again 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.



	Total Threats + Op...
25%	1,134,893.87
30%	1,204,831.14
35%	1,271,435.62
40%	1,335,769.26
45%	1,400,676.09
50%	1,463,385.07
55%	1,527,490.21
60%	1,593,858.89
65%	1,664,717.23
70%	1,742,132.80
75%	1,824,696.12
80%	1,917,316.90
90%	2,175,066.81
95%	2,406,030.16
97.5%	2,639,520.78
99%	3,053,351.67

Figure 4Total 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	$1,742,133
Total at 80% CL	$1,917,317
Total at 90% CL	$2,175,067

Table 3 Results of the @risk monte carlo analysis of cost impacts from discrete risks. IceCube Upgrade uses the 80% confidence level in calculating 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.

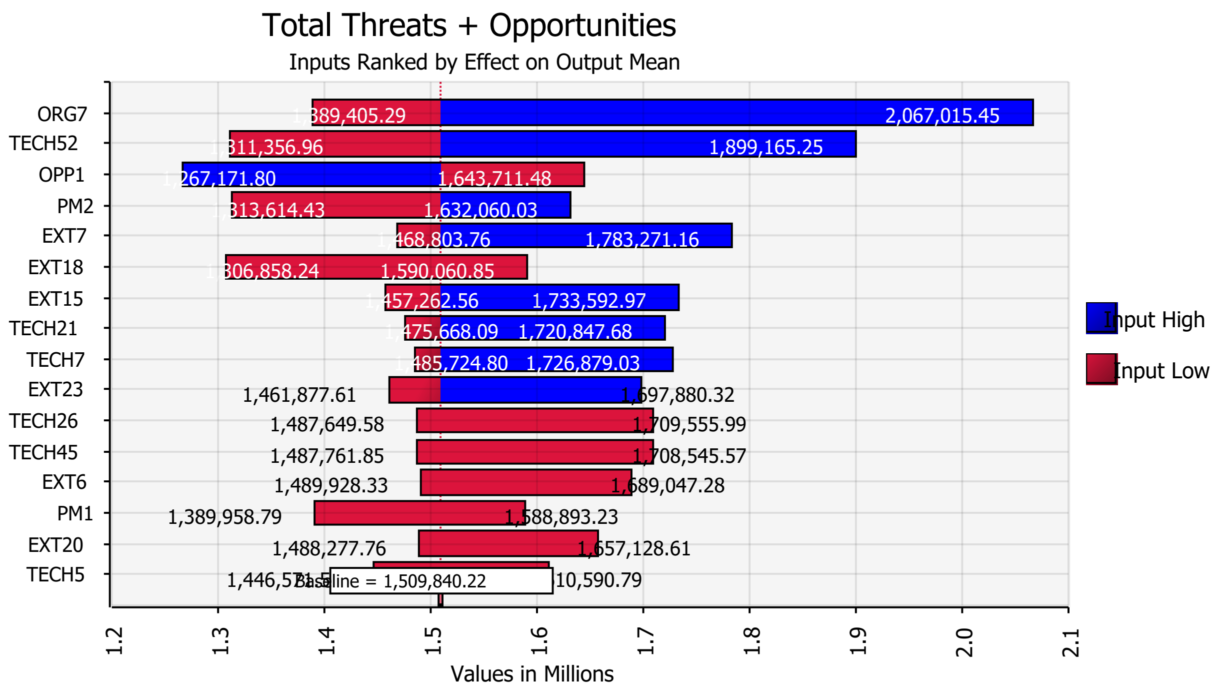


Figure 5 Top risks in terms of cost impact. For more information on the risks and how they were estimated, see the risk register.

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).