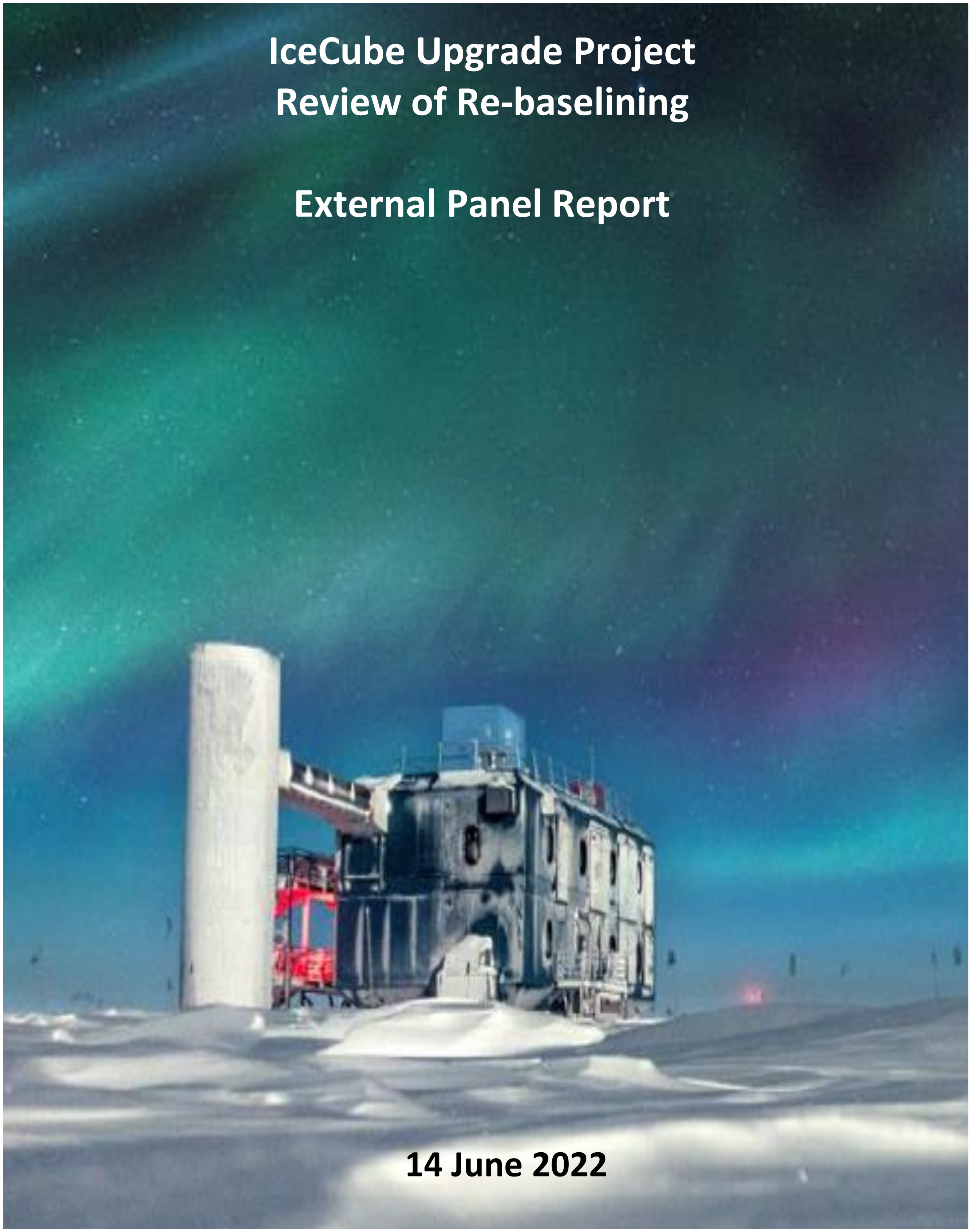

IceCube Upgrade Project
Review of Re-baselining

External Panel Report

14 June 2022

PREFACE

The National Science Foundation (NSF) established a panel to provide an external review of the re-baselining effort by the IceCube Neutrino Observatory (ICNO) upgrade (IC/U) project which was approved for construction in October 2018. The project would add seven additional strings of detectors in the bottom half of the center of the current 86 string detector. ICNO and its operators are an active component of the U.S. Antarctic Program (USAP) which is managed by NSF. This panel met with NSF and IC/U project personnel 26-28 April 2021.

The ICNO, located at the Amundsen-Scott South Pole Station in Antarctica (Station), utilizes an array of surface detectors and photosensors distributed through one cubic kilometer of deep ice to observe neutrinos from astrophysical sources. ICNO has been in full operation since 2010. The IC/U project (Project), when completed, will consist of seven new columns (or “strings”) of photosensors, densely embedded near the bottom center of the existing ICNO sensor array. The Project will include new calibration devices designed to enable a better understanding of the optical properties of glacial ice and the detector’s response to signals from muons traversing the array. The improved calibration resulting from the Project will be applied to the entire archive of IceCube data collected over the last ten years, thereby improving the angular and spatial resolution of the detected astrophysical neutrino events and facilitating ICNO’s search for point sources of high energy neutrinos. The Project will also provide world-leading sensitivity to neutrino oscillations and will enable unique measurements of tau neutrino properties.

The Project is currently in project year 4 (PY4) with on-ice work at the South Pole suspended over the last two years due to restrictions imposed by the COVID-19 pandemic. A Logistics Review was held in November 2021 to examine the management of and the logistical needs for the Project given the two years of suspended on-ice work. In addition, the Project has worked with the NSF/OPP Antarctic Infrastructure and Logistics (AIL) team, which has identified a path forward to support the project: one more season with no on-ice work (FY23, austral 2022-23 Summer) followed by three seasons of on-ice work in FY24, FY25, and FY26. With this significant change to the overall Project schedule and an anticipated change in total Project costs, a re-baseline review is needed to assess the Project’s plan from FY23 to the completion of the Project.

The review panel (Panel) was charged with evaluating the IC/U Project’s current plans to complete the scope that was originally proposed to NSF (PHY-1719277) and subsequently awarded. The Panel was not asked to re-review the Project as a whole, but rather to focus upon elements relevant for Project completion and those elements modified in response to deviations in cost and schedule that have been experienced. The Panel was asked to provide NSF with an evaluation of the likelihood that the remaining Project scope as proposed can be delivered within the parameters defined in the Project’s re-baseline definition, including the adequacy of cost contingency, schedule contingency, and risk and scope management plans, and to provide the Project with key recommendations that will improve and increase the likelihood of Project success. Additionally, NSF requested the Panel to provide answers to specific questions posed in the Panel’s charge. The Panel was tasked with producing a written report presenting its findings, comments, and recommendations.

The Panel members appreciate the opportunity and privilege of interacting with the IC/U team and NSF program managers in conducting this review. We are:

Mr. George Blaisdell, U.S. Army Cold Regions R &E Laboratory (retired)
glblaisdell@gmail.com; *Panel Co-Chair*

Prof. Donald L. Hartill, Dept. of Physics, Cornell University
dlh13@cornell.edu; *Panel Co-Chair*

Dr. Marion Dierickx, CFA & Harvard U., BICEP Group
mdierickx@cfa.harvard.edu

Mr. Ken Fouts, SLAC, Super-CDMS SNOLAB project manager
kfouts@slac.stanford.edu

Dr. Paul O'Connor, Brookhaven National Laboratory
poc@bnl.gov

Mr. Lee Pearson, Independent Consultant
lee.pearson@live.com

Dr. Alexandra Rahlin, Fermilab, SPT and SPIDER, frm SP station lead
arahlin@fnal.gov

Mr. Blaise Stephanus, Dartmouth College, Polar Consultant
blaise.j.stephanus@dartmouth.edu

Dr. Lucas Taylor, Fermilab/CMS and PIP-II, Project/Risk Manager
lucas.taylor@cern.ch

Mr. Steve Theno, Independent Engineering Contractor
stevethenoak@gmail.com

Contents

INTRODUCTION

Once formed, we (the Panel) received documents from the IceCube Neutrino Observatory Upgrade (IC/U) project team. These materials covered a wide range of Project plans in detail. The selection of materials was likely driven by the group of questions that formed NSF's charge to us and was provided to the IC/U team in early April 2022. The provided documents were reviewed by us prior to a three-day virtual meeting.

Days one and two of the meetings (26, 27 April) were consumed with presentations from the IC/U team. Limited question and answer sessions took place after each presentation, with detailed written questions presented in writing to the Project at the end of each of these days. Wrap-up questions to and answers from the IC/U team, including more detailed replies to some of our earlier questions, occupied the final day of meetings (28 April). At the conclusion of the meeting, the Panel presented a summary of its initial impressions of the re-baselining plan for the Project. That summary forms the basis for this report.

FINDINGS

We highly commend the Project team on their presentations and responses to our questions. Not surprisingly, the Panel, with more than 200 years of subject matter expertise, drilled deeply with its questions. Nonetheless, the responsiveness and attitude of the Project team made the review productive and enjoyable for the Panel.

The physics reach of these seven new strings will increase by an order of magnitude the number of low energy neutrino events down to 5 GeV. This will enable ICNO to perform the world's best measurement of tau neutrino appearance and the world's most stringent test of unitarity in the tau sector of the Pontecorvo-Maki-Nakagawa-Sakata (PMNS) matrix. The PMNS matrix describes all known neutrino oscillation behavior, and deviations from unitarity would be evidence for new physics.

As a bottom-line-up-front (BLUF) statement, the Panel has high confidence that the scope of the Project can be delivered, provided the manageable concerns reflected in this summary are addressed in a timely fashion.

Our findings are divided into seven sections corresponding to categories defined in our charge. The final category presents replies to each of the questions contained in our charge.

Science and Technical Status

The science team is experienced at all levels and continues to demonstrate vast institutional knowledge, teamwork, and dedication. The addition of a Project Director has improved team performance. Most of the technical staff, particularly at the WBS Level 2, have had extensive experience in the original (Generation 1) IceCube project including multiple deployments to

Antarctica. The Project's presentations were complete and showed a high degree of competence and dedication to Project success.

The project demonstrates clearly defined goals and technical understanding. These are found consistently throughout the Project staff with which we interacted.

The three years of Project delay due to COVID-19 have led to further maturing of the technical scope, including understanding limitations of current datasets (e.g., Generation 1 operations and scientific results) and refinements in calibration strategies.

Collaborating institutions appear well-integrated as part of the overall Project team, and the majority of their in-kind contributions are ahead of schedule. Specifically, a large fraction of the work for sensors (WBS 1.3) is contributed by un-costed international and university partners. In many cases the hardware deliverables are either completed, in production, or well-advanced. However, the impact of possible loss of in-kind labor contributed by key personnel (e.g. mainboard electrical engineers, software simulation experts, etc.) should be covered by appropriate risk register entries.

The enhanced hot water drill system is essential for the installation of the new detector strings and is currently stored at the South Pole Station. A new hose is needed and was a major concern a year ago because it would be manufactured in Italy (which was under Covid Lockdown at the time). The manufacturer was able to produce the hose and it is currently in McMurdo.

The Drill Control System is all new, potentially a critical path item, a significant cost item, and is a source for a number of identified risks. The current implementation plan defines a structured path for implementation. However, the Project is encouraged to consider further acceleration of the software development and bench testing off-continent to debug and optimize it before deployment.

There is a nearly complete drill mockup at PSL in Madison and nearly all the software can be validated there. The Project is encouraged to finish the software development and carry out the tests early to remove this uncertainty.

The majority of IC/U technical elements (WBS 1.3-1.6) are at a high level of maturity. Flowdowns, interface definitions, verification and validation tests are documented and clearly capture the design and methods to ensure that performance goals are met.

Project Management

The Project Director and Project Manager have brought with them extensive experience from their leadership roles on large projects prior to joining IC/U.

The Project Office urgently needs a Project Controls person/Master Scheduler with EVMS experience. This person needs appropriate authority and support from the Project Office.

Project management tools do not provide seamless support for integrated scheduling, cost estimating and risk analysis. While the Panel found reasonable project controls from the several tools being used by the Project, we are very concerned about the potential for late or missing recognition of schedule risks. An overwhelming advantage of an integrated project management tool is the immediate awareness by all Project managers of the ripple effects of schedule risks.

The new Project Execution Plan fits nicely into the logistics guidance from USAP/ASC and there is evidence of ongoing and effective communication between the Project and USAP/ASC.

Cost

The Panel performed high-level drill-down on Bases of Estimates (BOEs) with emphasis on the Project Management Office (PMO). Estimates are generally comprehensive and support the scope of work.

The Key Assumptions and BOE documents would benefit from some general scrubbing. For example, this involves making sure BOE budgets either match supporting vendor quotes/invoices or have any differences explained in the BOEs. Where the analogy method is used, the logic showing the reasons for deviation from the history needs to be included in the BOE. In general, the project should be able to identify each step used to produce the resulting budget (Show how the budget is derived from source pricing material i.e., history, prior experience, vendor quotes, invoices etc.).

Minor omissions in the BOEs were detected and pointed out to the project team. They include:

- (Overall) Travel is not escalated in the outyears.
- BOE 1.1 SmartSheet seat cost is not escalated in the outyears
- No inflation was added for shipping costs in the outyears
- BOE 1.2.1 – Travel BOEs have to better documents the reasons the number and type of staff selected for international and domestic trips (For example: why are 5 people budgeted to go to an ASC meeting)
- BOE 1.3.3 PDOM – clean up quote and add any necessary narrative.
- BOE 1.1 project management staff ramp down needs to be better documented. Include reasons for the staff reductions. Is the effort to be managed falling off?

The Panel's charge questions, and their responses (see below) give a detailed accounting of omissions or miscommunication found in our cost drill down.

The Panel has concern about the planned downsizing of the PM staff near the end of the Project, believing it is too aggressive. In discussion with the Project, they responded with historical precedence (from Generation 1) supporting the outyear downsizing timing and their assessment that the staff task loading was reasonable. The Panel recommends revisiting the early downsizing of the PM staff to determine if past experience was successful because of factors it controlled and can be reasonably assumed to be controllable in the current Project.

Inefficiencies caused by COVID-19 impacted multiple cost and schedule drivers. COVID-19 caused on-ice cancellations and delays, led to a closing/slow-down in the University of Wisconsin's Physical Science Laboratory (PSL), led to parts delays and unavailability, and increased staff turnover. Those actions had a profound effect on the Project as originally costed. These factors have forced the need for a considerable budget increase (re-baseline).

The Project team's past experience has significantly increased the project's technical maturity and reduced the risk of cost growth due to non-logistics factors.

Project drilling staffing (28 field staff, with 14 experienced) needed for the Project's final field season may be particularly challenging in the current labor environment and represents a challenge to both cost and schedule control.

The "manual" calculation of EVMS metrics from Smartsheet could produce incorrect cost and schedule variance information that could create blind spots for Project management.

Schedule

The Project schedule includes all the Project scope, resources and costs. Comprehensive scope is reflected in the WBS, each WBS element has a clear owner, and the WBS dictionary is complete. Resource loading is evident, and histograms of resource forecasts were produced. Significant improvement in the schedule was observed by Panelists with historical perspective on this Project.

The use of Smartsheet as the scheduling tool has some shortcomings, such as the disconnect between time-phasing of activities (Gantt chart) and the time-phasing of the resource loading. The Project's schedule logic needs significant work to implement the missing logic such that all activities have logical predecessor and successor activities, thereby ensuring that the schedule predictions are credible.

The master schedule is currently managed using distinct spreadsheets for schedule, and for cost and resources. When schedule information is updated and forecast dates are adjusted, the forecast resource usage and cost information have to be updated separately and manually. This is a weakness that should be addressed.

The lack of tight logic in the schedule means that the current schedule cannot be used to perform rapid and credible what-if schedule studies and schedule risk assessments. This needs to be addressed.

Given the numerous gaps in the activity logic and lack of integration of source data (schedule, resource, and cost information are not automatically linked), there is a risk that the time phasing of the planned value forecast could be inaccurate. A detailed monthly forecast of planned value for the remainder of the Project was not provided and details were difficult to assess given the format in which the supporting information was provided (Cost Workbook and summary EV forecasts by PY).

Logistics

The Project team demonstrated rigorous planning within the implementation strategy defined by NSF. Documentation for cargo movement is comprehensive and shows clear methodology.

Installation activities and field seasons appear well-planned and adequately staffed.

Cargo Float Tables flag items with marginal float, but do not include an explanation. A column to capture the reason and what action is being taken would be helpful.

The float information in the Cargo Float Tables did not appear to be derived directly from a master schedule. It is important for all such schedule information to be derived directly from the latest master schedule.

Risk Management

The Project team is very experienced and clearly understands their risks. The Project team is commended for their initial analysis and should ensure that risks are regularly revisited as part of their regular management processes. Significant improvement in the risk analysis was observed by Panelists with historical perspective on this Project.

The Risk Management Plan is compliant with best practice but would benefit from describing some of the Project-specific risk-related activities.

The project has assessed risks across the project scope, including risks related to off-project in-kind deliverables from international partners. These are fairly well documented in a risk register including risk mitigation actions, post-mitigated probabilities, cost impacts and schedule impacts.

Major technical risks have been identified and mitigation planning is well advanced, such as: EXT9 -- schedule impact of semiconductor supply chain disruptions on the mDOM motherboard; and TECH38 -- concerns about mechanical integrity of Main Cable Assembly prototypes from the preferred vendors.

Alternative designs for some of the circuit boards in the mDOM optical modules are an appropriate mitigation against the risk of possible delays in the supply chain for certain electronic components.

The risk register would benefit from the removal of outdated data (e.g. to a backup copy), for example, obsolete risks, pre-mitigated (and possibly out-of-date) risk assessments. The project should focus on quantitative values for probabilities (percent) and minimum, likely, and maximum cost impacts (dollars) and schedule impacts (months of delay to successor tasks), rather than binning this information and hence losing information. The risk ranking matrix should be reviewed to ensure the top ranked risks align with the top concerns of Project management.

The risk analysis appropriately aggregates the total cost risk using a Monte Carlo model. The risk register identifies a significant number of risks and a significant number of post-mitigated High risks. The use of the tornado plot to rank the risks identifies only the risks with the highest cost in the overall ranking. With limited time on-ice for each season, the Panel expected that some schedule risks would be more prominent in the overall risk ranking. Project management should consider developing a more balanced strategy for considering cost and schedule in project risk analysis.

Understanding schedule risk and available float (at a given confidence level) in the highly constrained schedule is critical to project success; significant work is needed on the existing schedule logic before a credible schedule risk analysis can be performed. No schedule risk analysis nor assessment of needed schedule contingency was presented. This is a notable omission that needs to be addressed. Ideally a risk MC based on the full schedule would be performed. If this is not possible, the project should consider toy MC modeling of subsets of sequential of risks on the critical path or prior to key milestones (e.g. readiness for each field season). At the very least, the project should study various what-if scenarios (after the missing schedule logic has been fixed) to assess the potential consequences of the main schedule risks.

The Project should closely monitor upward Materials and Supplies (M&S) and labor inflation trends caused by Covid-19, supply and logistics chain issues, and geopolitical uncertainties, to ensure that the potential impacts are adequately captured in risks PM1 and PM2, allowing for: general inflation trends (e.g., PCE and BLS ECI indexes); commodity prices; specific M&S price concerns (e.g., electronics); and labor escalation due to upward wage pressure and tight labor markets.

The nature of the scope of the Project limits the available descope options. Additionally, the options that exist are unlikely to be known to be necessary until the Project's final field season. Descope options that exist for the final field season save some schedule but not cost and degrade science capabilities.

The effort for integration of calibration instruments is comprehensive and well-planned. However, this activity could benefit from further planning with regard to descope options, should the higher-risk elements of the upgrade require changes. For example, incorporate a detailed plan for which / how many instruments to deploy if the number of deployed strings must be reduced.

The main cable assembly may require an additional external load support. This is tracked as a risk. The Panel recommend that the implementation management group follows this closely as it could impact hardware and procedures managed under the installation group.

While drilling and installation are based on successful Generation 1 methodologies and experience (a significant strength), IC/U does introduce implementation risks (holes and strings are scaled up, new main cable assembly, revised procedures, etc.). With all seven holes planned to be accomplished in a single field season, there is little margin to accommodate delays and procedure learning curves. This risk is mitigated by the ability to descope one or even two holes while still achieving the defined project success.

Charge Questions Response from Panel

Science and Technical Status (ST)

- ST1: Does the Panel find areas of concern regarding the definition and completeness of the technical scope as it flows down from the science goals of the upgrade?

  Relative to WBS 1.2 Implementation, the Project Team demonstrated a very strong understanding of the technical scope and presented a well-developed plan for implementation.

  While the scope of work for reworking the EHWD, startup, commissioning, testing, placing in operation and operating seem to be very well understood by the core drill team, more formal documentation of the work plan and detailed activity tasks is recommended. This would enhance confidence in the level of planning, improve on ice efficiency and provides a reference resource for the team, especially if a core team member became unavailable.

  The Project schedule is comprehensive, the scope is reflected in the WBS, each WBS node has a clear owner, and the WBS dictionary is complete. Resource loading is evident, and histograms of resource forecasts were produced. Significant improvement in the schedule was observed by panelists with historical perspective on this project. Durations appear to be appropriate from what was observed but there are no documented rules providing guidance on minimum/maximum duration for non-placeholder/non-LOE activities.

  Activities are only partially logically sequenced and there are many activities that have been "calendared" using constraints and that are missing predecessor and/or successor relationships. The schedule should have predecessor and successor relationships defined for each activity. The impact of this gap is twofold. One is that float is inaccurate and open-ended tasks show an excessive amount of float. Second, when an open-ended task incurs a delay, the impact is not reflected in the downstream activities. While the project team clearly understands their work and is on top of the management, this missing logic introduces risk that delay impact is overlooked. Moreover, missing logic means that the important schedule what-if studies and the schedule risk and contingency analyses are not credible.

- ST2: Are the updated milestones associated within each WBS element clearly defined and do they aid the overall project management?

  Relative to WBS 1.2 Implementation, the Project Team noted they have established 30 L2 milestones and 296 internal milestones to aid in project management. The samples presented were clear, well defined and seemed logical.

  The project team has been able to support earned value reporting requirements to date. The schedule is resource and cost loaded. Overall schedule and major milestones appear reasonable.

  Given gaps in logical sequencing and lack of integration of source data (schedule, resource, and cost information are not automatically linked), there is risk that the time phasing of the planned value forecast is inaccurate. A detailed monthly forecast of planned value for the remainder of the project was not provided and details were difficult to assess given the format in which the supporting information was provided (Cost Workbook & summary EV forecasts by PY). Additionally, gaps in logical sequencing prevent assessment of schedule for adequate float and contingency.

  Finally, Smartsheets appears not to be a well-integrated tool for managing cost and schedule. General capabilities of an Integrated Master Schedule need to be managed in separate spreadsheets, one for schedule, and another for cost and resources. When schedule information is updated and forecast dates are adjusted, the forecast resource usage and cost information have to be updated separately and manually. This increases the potential for errors and makes it difficult to create reliable earned value data. It would be better if the schedule, resource, and cost information could be maintained in a single integrated tool. If this is not possible, the project office support for Smartsheets should be strengthened to ensure the integrated cost and schedule data are synchronized and consistent at all times.

- ST3: Which components have the greatest technical risk and uncertainty? What level is that risk and uncertainty, and are mitigation plans in place to reduce possible impacts?

  The main cable assembly may require an additional external support element to help reduce the load on the cable when installed. This is noted as a risk item and should be resolved once the prototype cable can be tested. The Implementation Team (WBS 1.2) is confident they can accommodate a cable configuration with an external support element. However, it is recommended Implementation follow this closely as it will likely require additional install equipment and impact install hardware and procedures.

  The Drill Control System (WBS 1.2) is all new. It is on the critical path, a significant cost item and is the source for a number of identified risks. The current implementation plan defines a logical, sequential path for implementation. We recommend the Project considers further acceleration of the software development and bench testing off continent to debug and optimize as much as possible before it is required to ship.

- ST4: Are the number of spares and associated level of supplies appropriate for each of the systems?

  Relative to WBS 1.2 Implementation, the core element is the EHWD. The EHWD modules and components consist of a mix of simplex systems, duplex systems, systems with built-in spares and systems with spares in ready storage. The Implementation Team is reworking the overall system based on a field condition recon accomplished in 2018/2019, refurbishing equipment and systems. Spares, supplies, materials and consumables, both for the rework activities and drilling/installation activities is being planned based on the experience of the core drill and installation team. There is high confidence the spares, supplies and consumables planned are appropriate.

  While there is high confidence in the ability of the team to assemble the spares, supplies and consumables required for the work, more formal documentation linking the spares, supplies and consumables to the rework and drilling tasks and work plans is recommended. This would enhance confidence in the level of planning and provides a reference resource for the team.

  In-kind project work is appropriately modeled in the schedule as (un-costed) activities and milestones.

  It is not possible to assess the float, critical path, and the schedule contingency needs without more complete schedule logic (predecessor and successor relationships defined for each activity). This missing logic presents an increased risk that schedule issues result in real schedule delays. The expertise of the project team is, however, significant and, once their experience is reflected in a more robust schedule, credible schedule risk analyses can be performed that will help ensure the project stays on schedule.

- ST5: Are the interfaces and overall system level engineering adequate for project success?

  Relative to WBS 1.2 Implementation, The Implementation Team demonstrated a clear understanding of the interfaces within the project. Notably, the Team has captured in the project schedule the discrete activities requested of USAP – ASC support during the field seasons. The Team demonstrated a clear understanding of the overall system engineering requirements. The Team summarized the work accomplished and the work remaining. In particular, the hole thermal modeling and fuel analysis are detailed and well documented. The system level engineering work remaining is well defined and logically phased to support the field activities.

  With respect to the interfaces between IC/U and USAP Support, the USAP Support requirements are coordinated with scheduled periodic meetings between IC/U personnel and USAP - ASC contacts during project planning and through SIP reports submitted prior to Field Seasons. Furthermore, IC/U has captured USAP – ASC support activities on the project schedule, including dates and durations. However, it is recommended that pertinent details pertaining to the tasks (sizes, capacities, configurations, special tools or equipment, special requirements, etc.) be documented and linked to the scheduled activity for future reference.

- ST6: Are the project's updated plans and processes for ensuring technical readiness in place and adequate?
  - ST6a: For the refurbishment of the hot water drill, setting up the drill camp, and main drilling.

    Yes. The Project Team presented a very strong and detailed plan for refurbishment of the EHWD; and for startup, commissioning, testing, placing in operation and for drilling operations. The Team has taken advantage of the recon work accomplished in 2018/2019 to solidify the scope of refurbishment work, to complete some work off continent and to position major EHWD components for early transportation to Pole. The Team presented samples of well thought out on ice workflow plans and on ice staffing plans. The Team highlighted key remaining preparation tasks including: additional systems engineering, procurement, development of SOPs, development of training plans and personnel recruitment and training, along with a logical sequence for accomplishing those tasks. This level of readiness applies to the sensor string installation plans and processes as well.

  - ST6b: For the communications, power, and timing systems.

    Yes. The communications, power and timing systems will be sufficient to integrate the upgrade components (new DOMs, calibration sensors) into the IceCube data acquisition system.

  - ST6c: For characterization and calibration systems. Is the project on track to achieve requirements for an improvement in the precision of pointing to cosmic sources?

    Yes. The additional sensors included with the upgrade will provide comprehensive improvements to instrument characterization and calibration. These components are largely in-kind contributions and appear to be on schedule for timely delivery.

  - ST6d: For the M&O data integration systems. Are there concerns with future data transmittal?

    No such concerns. The increased data transmittal is small enough that it should fit within existing capabilities; data transmittal needs can also be adjusted (descoped) if required.

- ST7: Is the project office adequately monitoring technical contributions from non-NSF funded partners and integrating those into the revised schedule?

  Yes. Progress and convergence of inputs from international partners with in-kind contributions appears to be an area of significant focus for the project. Overall, the vast majority of technical contributions from non-NSF partners appear to be ahead of schedule for deployment; areas where that is not the case are clearly identified and monitored, with possible mitigation strategies outlined.

Costs (C)

- C1: Evaluate the appropriateness of the estimating method employed and the degree to which the estimates and their accompanying justifications (BOEs) to determine if the budget is comprehensive and traceable.

  Reply included with answer to C2.

- C2: Are key assumptions well-documented, comprehensive, and current?

  A drill down was conducted on the BOEs, justifications, and accompanying quotes (where applicable). Minor issues were discovered (provided on request). However, in general, the estimates and their accompanying justifications (BOEs) appear comprehensive and traceable. Key cost assumptions with the exceptions noted (provided on request) appear comprehensive and current.

- C3: Assess the appropriateness of the major level of effort components of the WBS, especially in the project office, as a proportion of the total budget needed to complete the project.

  Reply included with answer to C4.

- C4: Are full time equivalent levels of labor well documented and justified, and is the labor mix appropriate?

  The overall Project office budget is in the range of acceptable project management percentages (PM to Total Budget). There were concerns that the reductions of FY-24-26 staff levels might reduce project management capabilities during the Project's execution phase. Detailed questions were presented to the Project (provided on request). The Project responded that IceCube Generation 1 staffing supported such reductions and that the remaining staff would be appropriate during execution.

  Levels of labor identified in our drill down were documented and justified.

- C5: Is the requested budget as it deviates from the original award understandable? Are there large cost deviations beyond a reasonable level of inefficiency during the COVID-19 pandemic periods?

  The Project basis of estimate justifications reviewed in the drill down included estimates based on analogy. The drill down questioned estimates based on expert judgement in areas where the Panel thought analogy to the original award could have been used. The Project's reasons for not using analogy in the questioned areas seemed justified.

  It was difficult to separate inefficiencies caused by COVID-19 impacts from other drivers. COVID-19 had on-ice cancelations and delays, led to a closing/slow-down in the University of Wisconsin's Physical Science Laboratory (PSL), led to parts delays and unavailability's, and increased staff turnover. Those actions had a profound effect on the Project.

- C6: Are the cost estimating methods and project management in place to cover risks should they materialize and ensure that risk materializing is captured appropriately with contingency?

  For cost (but not schedule) contingency, it appears that they do. The Project's estimates include risk-based contingency. In addition, the Project has a risk management plan, a risk register, and has had successful training of their WBS Level 2 Managers. These tools and training are at beginning stages and need to be refined. The overall contingency seems to be consistent with their overall level of project maturity for project type risks.

Risk-based cost contingency is not allocated to cover NSF type risks (logistics issues, funding shortfalls/delays). The assumptions about which risks are covered by NSF should be agreed between the Project and NSF and suitably documented.

- C7: Are the costs associated with in-kind contributions and subawards estimated, well documented, and mapped to the work breakdown structure?

  This is an area in which the Project can improve. Key subaward delivery milestones are included in the schedule. However, the Panel is unsure if subaward task documentation and risk identification are included in the central Project's PM tools. In our judgement these may have gaps that should be identified and fixed.

- C8: Are project resources effectively allocated to all personnel tasks, activities, and equipment and material and supply costs and are these well-defined and reasonably estimated?

  IceCube's Generation 1 experience and proven processes have now been extended to this enhancement. The drill down confirmed these estimating processes are well employed. Based on the drill down these seem reasonable.

Schedule (S)

- S1: Has the project developed a comprehensive resource-loaded schedule with logically sequenced activities of appropriate durations, clearly identified interdependencies, milestones, Antarctic contractor activities and resources, and a valid critical path? Does the schedule adhere to the GAO Schedule Assessment Guide – comprehensive, well-constructed, credible, and controlled?

  The project schedule is comprehensive, the scope is reflected in the WBS, each WBS node has a clear owner, and the WBS dictionary is complete. Resource loading is evident, and histograms of resource forecasts were produced. Significant improvement in the schedule was observed by panelists with historical perspective on this project. Durations appear to be appropriate from what was observed but there are no documented rules providing guidance on minimum/maximum duration for non-placeholder/non-LOE activities. However, the Panel did not have access to the schedule in a standard format (e.g., XER file) that permits interactive scrutiny; therefore, the schedule could not be fully reviewed. It would be helpful for future reviews to have an interactive version of the schedule.

  Activities appear to be logically sequenced but there are still many activities that have been "calendared" using constraints and that are missing predecessor and/or successor relationships. The schedule should have predecessor and successor relationships defined for each activity. The impact of this gap is twofold. One is that float is inaccurate and open-ended tasks show an excessive amount of float. Second, when an open-ended task incurs a delay, the impact is not reflected in the downstream activities. While the project team clearly understands their work and is on top of the management, this missing logic introduces risk that delay impact is overlooked.

  For example, as activity dates change, dependent activities do not move correctly, and schedule dates, the critical path, and float values are not credible. It is imperative that the Project team systematically reviews every single activity and implements the correct schedule logic. This is particularly important for this project given the challenge of fixed stringent external schedule constraints related to logistics and the three field seasons.

- S2: Will the revised schedule allow the project team to create reliable earned value data to monitor progress against plans, forecast completion, and maintain the performance measurement baseline? Do the overall schedule and major milestones appear reasonable given the unique environmental and logistical considerations? Does the schedule include adequate float and contingency?

  The Project team has been able to support earned value reporting requirements to date. The schedule is resource and cost loaded. Overall schedule and major milestones appear reasonable. However, gaps in logical sequencing and non-integration of source data (schedule, resource, and cost information not automatically linked), there is risk that the time phasing of the planned value forecast could be inaccurate. A detailed monthly forecast of planned value for the remainder of the project was not provided and details were difficult to assess given the format in which the supporting information was provided (Cost Workbook and Summary EV forecasts by PY).

  Smartsheets does not appear to capture the capabilities of an Integrated Master Schedule, but rather the Project is managed in separate spreadsheets (one for Schedule, another for Cost and Resources). When schedule information is updated and forecast dates are adjusted, the forecast resource usage and cost information must be updated separately and manually. This increases the potential for errors and makes it difficult to create reliable earned value data. It would be better if the schedule, resource, and cost information could be maintained in a single tool.

  The missing schedule logic means that the current schedule cannot yet be used *reliably* to monitor project progress. Once the missing logic has been implemented, the statused schedule will become more usefully predictive, the float calculations will be more credible, and the adequacy of the schedule contingency can be assessed.

- S3: Are there plans for cost-efficient use of personnel in FY23 (no-ice work) considering "standing army" costs and the need to have a fully prepared team working towards Field Season 1?

  Relative to WBS 1.2 Implementation, the team presented concise summaries of the off-ice work completed to date and the off-ice work to be completed FY23 (as well as future off-ice seasons). The off-ice work to be completed seemed appropriate and logically sequenced. It was clear the team was aware that there needed to be a balance between the need to recruit, train and then retain on-ice personnel for future seasons versus cost control.

- S4: Is the critical path schedule defined for completion of the project? How vulnerable is the critical path to risk and uncertainty, and are there appropriate risk mitigation plans? Are schedule dependencies related to in-kind contributions clearly identified?

  The missing schedule logic means that the critical path is not yet reliably defined. Thus, it is difficult to assess the critical path without more complete logic and meaningful float calculations for each remaining activity. This presents an increased risk that missed logic could result in schedule delays. However, given the experience and expertise of the Project team, there is probably less vulnerability of the critical path being delayed due to known risks and uncertainties. In-kind Project work is captured in the WBS and task level detail is defined and linked.

It is not clear that the schedule in its current state can be used to model "what-if" scenarios related to the implementation of risk response plans. Once the predecessor and successor relationships have been defined for each activity, the schedule could be used to perform time impact analysis and total float could be measured before and after the implementation of risk response plan to put a more objective measure around the potential schedule impact of known risks.

In-kind contributions are included in the schedule (as uncosted activities), milestones, and in the risk register. As the schedule is scrubbed and the risk analysis is developed, the Project should systematically review all in-kind dependencies and risks to ensure completeness.

- S5: Is the revised project completion clear and well defined? Are the updated plans and commitments adequate for post-project activities such as moving retrograde equipment and cargo north?

  Project completion is clear and well defined. This includes descope options (i.e., reduction in number of deployed sensors and reduction in number of total deployed sensor strings) that would still yield project success.

  USAP and IC/U cargo planning includes retrograde capacity in FY 26 and FY27. The project plans currently include retrograding the drill hose (which is DNDF) in FY26 and dismantling the SES and TOS. The SES and TOS modules will be winterized and prepared appropriately for either long term storage on Station or retrograde. No further action is in the current project scope.

Logistics (L)

- L1: Has the project responded adequately to the recommendations made by the Logistics Review Committee for the review held in November 2021 into the project plan and schedule, or adequately explained why a recommendation will not be implemented?

  As presented by the Project Team, the majority of recommendations have been implemented or are in progress and the action or proposed action seems appropriate. Two previous issues for which recommendations had been made did surface during this review as areas that warrant further consideration; 1) the use of a fully integrated master schedule and 2) more formal or rigorous documentation of field season work plans and equipment, materials, spares and consumables requirements.

- L2: Does the proposed cargo schedule align with NSF capabilities as provided to the project?

  Yes. The project team has demonstrated meticulous planning of cargo movement within the implementation strategy defined by NSF. The current IC/U cargo planning fits within the capabilities and constraints provided by NSF. There is surplus capacity available on the traverses each season. The two most challenging limitations are DNF/DNDF space at Pole, and LC-130 missions, the latter especially impacting fuel delivery. The DNF/DNDF limitation results in some cargo arriving Pole with very little available float. The LC-130 missions limitation results in the need for the last deliveries of fuel to occur during the final field season rather than being fully staged the season prior.

The Cargo Float Tables flag items with marginal float times (or float times less than a pre-established threshold). Recommend a Remarks column be added to capture the reason for the marginal float and what action is being taken to expand the float to the extent that is possible. The float values should be directly determined from the Project's integrated master schedule, once the missing logic has been implemented.

- L3: Does the proposed project on-ice labor effort align with NSF capabilities as provided?

  Yes, the current IC/U on-ice labor effort aligns with the population capacities provided by NSF. However, the Project's on-ice labor peak during the final field season requires the maximum available population capacity. The Project has noted this and intends to review work plans and procedures for any potential to reduce peak population requirements.

- L4: Are the logical links between the cargo movement schedule and on-ice labor reasonable and clearly stated?

  The Master Cargo Schedule identifies the Required On Site (ROS) date for all cargo. The general strategy of front-loading cargo movement is consistent with the proposed schedule for field seasons. The Cargo Float Tables indicate planned arrival on site versus required (float). The Integrated Master Schedule shows all scheduled tasks and activities. However, it is unclear what logic linkage exists between cargo ROS, cargo Float and scheduled tasks/activities other than by inspection.

- L5: Is UW's proposed schedule "traceable" – does it flow down from NSF logistical capabilities to project needs for logistical support, and then to adjustments that include risk mitigation? Does it define what needs to be where, and when, and does it define storage requirements (e.g. Do Not Deep Freeze) or other considerations that drive the schedule?

  The Cargo Master Schedule identifies for each piece of cargo the; origin, ship from location, planned shipment dates, required shipment dates, anticipated or required shipping method, required on site dates and storage requirements, among other items. Document #2021-003.3 ("IC/U Logistics – Cargo Estimation and Shipment Planning") demonstrates clear methodology and understanding of logistical support capabilities. The Logistics presentations summarized planned cargo loads versus available capacity by transportation mode and season. However, it is unclear what traceable linkage exists between the scheduled cargo requirements versus the available transportation modes and capacities each season, other than by inspection.

  Logistics Presentation, P11, slide 5 provides an overview of IC/U Planning Capacities based on OPP -AIL furnished allowances. A number of issues are captured in the footnotes in the Table. Recommend those issues be translated into action items and tracked for resolution.

- L6: Does the proposed project on-ice staffing plan support all the project tasks? Does the project have an appropriate level of redundancy in skillset, given the population limits at the station?

  Relative to WBS 1.2 Implementation; the proposed project staffing for drilling and install is based on the Generation 1 methodology and lessons learned. It appears to be well thought out. The drilling in particular is based on operating 3 crews 24/7. As such, there is inherent skill set redundancy across the field team. During the earlier field seasons during which equipment rework and seasonal equipment site setup is the major effort, the field team has been organized into multiple smaller work teams. According to the sample work plans presented and the resource designations, there is overlap in resource categories and skill sets amongst the work teams. During install, the greatest resource category utilizes members of the drill team. As such, there is skill set redundancies during this operation as well. Perhaps the weakest link in skill set redundancy resides with the Installation activity lead. If this lead was to become unavailable, no apparent back-up was noted.

- L7: Are the methods used to estimate the labor effort and overall schedule reasonable?

  Yes, relative to WBS 1.2 Implementation. The proposed staffing and task durations for drilling and install are based on the Generation 1 methodology and lessons learned. They have been modified and refined based on consideration of the differences between Generation 1 and IC/U (i.e., expanded hole drilling requirements, increased sensor string depth and sensor quantity, etc.). It appears to be logical and well thought out. The labor effort and schedule for the earlier field seasons during which equipment rework and seasonal equipment site setup are the major focus are based on earlier refurbishment recon assessments and rework planning as well as past experience from Generation 1. The effort and schedule have been assembled by senior personnel with extensive on-ice drilling and install experience. The sample work plans presented indicate the tasks, activities and durations have been well thought out. The BOE documentation captures the tasks and labor estimates.

- L8: Does the project clearly delineate the support activities needed of the Antarctic Support Contractor? Is this support included in the project schedule?

  Yes, relative to WBS 1.2 Implementation, the Implementation Team demonstrated a clear understanding of the support they will require from USAP – ASC and have captured the discrete support activities on the project schedule, including dates and durations. Support requirements coordination will continue with scheduled periodic meetings between IC/U personnel and USAP - ASC contacts during project planning and through SIP reports submitted prior to Field Seasons. However, it is recommended that pertinent details pertaining to the tasks (sizes, capacities, configurations, special tools or equipment, special requirements, etc.) be documented and linked to the scheduled activity for future reference.

Risk Management (R)

- R1: Is there an updated risk register with risk management plan that identifies risks and quantifies impacts and likelihood of their occurrence? Has the project adequately developed cost, schedule and scope contingency plans and are the associated costs robust, complete, and justified?

  The Risk Management Plan (RMP) describes a general best-practice risk process. The RMP should be updated to describe more specifically how the project actually manages risk. For example, summarize or cross-reference: management of partner in-kind risks, cargo sequence float management, on-ice risk management, and schedule risk analysis (e.g., push tests and what-if scenarios). The RMP should delineate the boundary between risks owned by the project, and risks owned by the NSF.

  The Risk Register captures a broad spectrum of risks across the project, including partner in-kind risks, and clearly reflects the extensive experience of the team. The register needs to be scrubbed to focus on the key risk data, for example: remove historical pre-mitigation risk data and retired risks; replace unwieldy risk binning with simple hard numbers, such as percentage probabilities and min/likely/max dollar impacts. Risks should be clearly linked to a handful of key milestones in the schedule, to enable what-if scenarios or simply risk MC models to be explored.

  The Risk Analysis appropriately aggregates costs risks using a simple MC based on risk probabilities and spreads of cost impacts, to determine the risk-based cost contingency. No corresponding analysis was presented for schedule risk. The effort required to develop a best-practice schedule risk MC is non-trivial. Nevertheless, the project should at a minimum assess schedule risk using what-if scenarios or using a toy MC to aggregate delays to key milestones from associated risks.

- R2: Are there avoidance and mitigation strategies with a proper balance between proposed resources needed for mitigating certain risks and acceptance of those risks not easily mitigated?

  The Risk Register documents pre-emptive risk mitigations (in the baseline plan) and reactive risk response plans. This documentation should be fleshed out in more detail. In addition, the basis of estimate justification for the post-mitigation risk probabilities and cost and schedule impacts should be summarized in the risk register and reviewed by suitable experts (other than the risk owner) to ensure overall coherence.

  While drilling and installation are based on Generation 1 methodologies and experience, IC/U does introduce implementation risks.

    - Holes are deeper and scaled up; none have previously been accomplished. A new step is involved to attempt to reduce or eliminate trapped air bubbles in the ice.
    - Installation hardware is scaled up; a new MCA will be used; additional sensors and special devices are placed on each string; possibly a second support rope on the cable which will modify installation equipment and

procedures; revised procedures at TOS; none have previously been accomplished.

With all 7 holes to be accomplished in a single season, there is little schedule margin to accommodate delays and procedural learning curves. However, this risk is mitigated by the ability to descope 1 or even 2 holes while still achieving defined project success.

- R3: Does the project's scope management plan include a time-phased estimate of available budget and or time from de-scoping options, based on key decision points?

  Descope options include a reduction in the number of strings or altering the parameters of the drilled holes. Even if these descopes are executed, the upgrades will still substantially enhance the performance of the existing IceCube detector.

- R4: Does the project appropriately consider budget and schedule impacts from in-kind contributions or partner performance risks?

  In-kind contributions are included in the schedule (as uncosted activities), milestones, and in the risk register. As the schedule is scrubbed and the risk analysis is developed, the Project should systematically review all in-kind dependencies and risks to ensure completeness.

- R5: Is the logic model supporting the cargo sequence and labor needs able to confidently estimate revised costs and scheduling, if needed, to replan completion of the project if surprises are encountered during the earlier part of the program? Can the team run the necessary scenarios in the required time?

  Not yet. The missing schedule logic needs to be implemented before what-if scenarios can be deemed credible.

- R6: Is there a mechanism for timely identification to take advantage of both challenges and opportunities that might arise during the project execution?

  The risk management processes as described should be adequate to address emerging risk threats and opportunities during project execution. Once the missing schedule logic has been implemented, the Project schedule may be used to rapidly perform what-if studies to respond to changing circumstances.

Project Management (M)

- M1: Are there any specific roles or teams that appear understaffed, overstaffed, or missing? Is the project management structure and the range of skills of key staff appropriate to confidently complete the project? Are there cognizant Control Account Managers (CAMs) identified for each work package?

  With the notable exception of the Project Director, the Project appears to be weak in terms of formal project management skills in the areas of cost estimating, scheduling, risk analysis and EVMS. More training of the project team in these areas (e.g. by physicist PMs from other projects) could be useful, for example to show the practical benefits of having a rigorous and logically-linked project schedule.

The Project Office appears understaffed. The current lack of a project controls lead / scheduler is particularly concerning. Appropriately, the Project is currently trying to hire such a person in an unfortunately challenging labor market. This role is key to building a credible schedule, and for executing EVMS practices that are predictive and facilitate management of the Project. Without the rigor and quick turnaround of monthly actuals in the project plan the ability to identify and correct cost and schedule performance issues in a timely manner is compromised.

With respect to project management structure: conditional 'yes' answer once the project controls shortfall is addressed.

- M2: Does the project have an adequate set of objectively measurable milestones for use by the PMO to measure and report progress, and to manage and recover variances if needed?

  Each L2 has a significant number of milestones in the schedule. The CAM's each update their schedule activities with percent complete every month. There are some drawbacks to this in that it tends to be subjective and has a tendency to be optimistic resulting in delays that are not realized until the very end of the activity.

  The project management tools do not provide seamless support for scheduling, cost estimating, and cost and schedule risk analysis. The tools and the quality of the associated data should be improved, so they may serve as a coherent master source of trusted cost and schedule data across the project and facilitate regular tasks such as earned-value management, float monitoring, and risk analyses.

- M3: Does the project employ adequate quality assurance practices?

  The project processes and procedures appear to be well documented and project personnel are familiar with the documented processes.

- M4: Is there evidence that the Project's Earned Value Management System (EVMS) is adequate to inform project performance and progress for decision-making?

  The project team uses schedule information from Smartsheet to calculate CPI and SPI. It was not evident that there is a rigorous process for the evaluation of cost and schedule variances and the management of corrective actions.

- M5: Is there an appropriate culture of safety with proper procedures in place for work performed under hazards?

  Yes, there is a strong culture of safety based on the teams extensive on-ice experience.

RECOMMENDATIONS

The Panel strongly supports the goals of the Project, which has a very strong case for re-baselining, once the following manageable recommendations have been addressed.

Recommendation 1: Review the comments in this Panel report and take action as deemed necessary.

Recommendation 2: Hire Project Controls effort to support key Project Office functions. These include more rigorous cost estimating, scheduling, EVMS reporting, and risk analysis. Consider engaging outside experts to provide ongoing guidance on such topics.

Recommendation 3: Improve Project Office processes to better integrate schedule, cost, and resource information. This will result in a more credible schedule and time-phased costs (e.g., float management, EVMS). The Project should implement rigorous processes that ensure Smartsheet (or a replacement) will demonstrably use activity durations and schedule logic to build a technically-driven schedule with credible early/late start/finish dates, critical path, and correct free float and total float values per activity. These improved processes should follow GAO/NSF best practices and allow quick "what-if" analysis capabilities. Consider engaging outside expertise to guide the team, review schedule changes, and help establish schedule quality metrics (reports) that drive improvements to the schedule.

Recommendation 4: Use EVMS reports and practices with the project team to help manage the Project. These include planned value, earned value, and actual costs per month (S-curves), as well as cost and schedule variances, variance analysis reports, and corrective action tracking.

Recommendation 5: Establish appropriate logic links for all activities in the schedule. This will enable the schedule to be used to: assess actual and needed float (e.g., prior to "ready to ship" milestones); perform critical path analysis; explore what-if scenarios; and analyze risks stochastically to determine risk drivers, and compute cost and schedule contingency needs at a high level of confidence.

Recommendation 6: Update the Risk Management Plan to describe more specifically how the project manages risk. For example, summarize or cross-reference management of partner in-kind risks, cargo sequence float management, on-ice risk management, and schedule risk analysis methodology. Clearly delineate the boundary between Project risks and risks owned by the NSF, and ensure this is reflected in the Risk Register.

Recommendation 7: Review and improve the Risk Register fields and associated data following best practices, taking the comments in this report into account, and focusing on quantitative (rather than binned) probabilities and impacts. Ensure the following are adequately described: risk mitigations, risk response plans, and the basis of estimates for risk probabilities and minimum, likely, and maximum cost and schedule impacts.

Recommendation 8: Establish a recognized methodology for performing schedule risk analysis and use it to assess risk-adjusted float and schedule contingency needs. This could consist of schedule risk what-if scenarios, toy Monte Carlo models to aggregate delays to key milestones from associated risks, or a Monte Carlo analysis of all the risks in the full schedule. Include the burn rate costs of risk delays (such as marching army and escalation costs) in the cost risk analysis.

Recommendation 9: Write up Standard Operating Procedures (SOPs), Training Plans (TP), and Field Work Plans (WP) and ensure that Project personnel are familiar with them prior to field deployment.