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Woods Hole Oceanographic Institution

NDSF Technical Operations Via Telecommunications

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Jonathan C. Howland, Willis Peligian, S. Adam Soule

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Technical Report

Funding was provided by the Nereus Legacy Fund at the Woods Hole Oceanographic Institution

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Approved for Distribution:

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Introduction

In 2015, the Woods Hole Oceanographic Institution (WHOI) commissioned an external study concerning the use of modern telecommunications and telepresence technologies in the potential reduction of manpower in National Deep Submergence Operations. That study has been completed, and the final report is attached as Appendix A. This Technical Report provides context for the study and makes the report accessible outside the Institution.

Background

Working for the benefit of the entire U.S. oceanographic community, WHOI operates a fleet of deep-sea exploration and discovery vehicles through the National Deep Submergence Facility (NDSF). These vehicles are the Human Occupied Vehicle *Alvin*, the Remotely Operated Vehicle *Jason*, and the Autonomous Underwater Vehicle *Sentry*. A description of these vehicles, their characteristics and capabilities, and of their use can be found on line at http://www.whoi.edu/main/ndsf.

All three of the vehicles typically rely upon vessels of the U.S academic fleet for necessary "host" services. While Alvin is hosted permanently aboard the R/V Atlantis, the other two vehicles operate in a "fly-away" mode, in which the vehicles and their portable infrastructure are transported via conventional freight services to host vessels in ports around the world. The vehicle operators travel to the departure port when the vehicles arrive, load and mobilize the equipment, and complete one or more research cruises aboard the vessel. The vehicles and infrastructure are then offloaded and shipped to their next destination, while the operators return to their point of origin, to eventually meet the vehicles again at the next port.

At sea operation of these complex vehicles requires an on-board crew of skilled engineers and technicians, as well as substantial support infrastructure ashore. Since one of the limiting factors in research vessel use is the available berth space available for on-board science parties including vehicle operations and support staff, there is substantial incentive for the NDSF to reduce its manning and free up berth space for additional scientists. Recent changes in the makeup of the U.S Academic fleet, including functional replacement of Global Class vessels with smaller Ocean and eventual Regional Class vessels add to this incentive.

The last thirty years have also seen increasing use of telecommunications and telepresence technologies in seagoing ocean sciences. It is not uncommon for scientists to participate virtually in at-sea operations from laboratories ashore, aided by satellite transmission of video and other data. Recognizing these trends, the National Science Foundation has vigorously supported this use by funding development and operation of HiSeasNet, a Scripps Institution of Oceanography based project that brings full time scalable Internet connections to the U.S. Oceanographic fleet. The National Oceanic and Atmospheric Administration (NOAA) has similarly funded extensive capabilities in scientific exploration through telepresence.

The Deep Submergence Science Committee (DESSC), a standing committee of the University National Oceanographic Laboratory System (UNOLS), recently formed a subcommittee to prepare recommendations publish a report on best practices for telepresence-enabled deep submergence science missions. Synergistic and parallel use by the NDSF vehicle operators of the same technologies could help make the case that telecommunications and telepresence offer significant advantages to Deep Submergence Sciences.

A wealth of scientific papers and presentations offer examples of telepresence and telecommunications use for both science and operations. NDSF asked the Willis Group (www.willisgroup.com) to consider the financial aspects of such use, specifically in the operational areas, and to provide recommendations on implementation and optimization of existing and near-term future telecommunications capabilities on UNOLS vessels, again focusing on deep submergence vehicle operational needs.

The Willis Group report, describing its findings and providing recommendations, is included as Appendix A to this report. An Excel® cost/benefit model was also delivered and is available upon request from WHOI.

Analysis

WHOI/NDSF provided five scenarios to the Willis Group for evaluation using the cost/benefit model provided to WHOI as part of the study. The first recommendations provided in the study concern those scenarios. Specifically, scenarios with net neutral costs or net cost savings were unconditionally recommended for implementation.

It is important to realize that NDSF interest is not limited to the five scenarios. They were provided as illustrative examples demonstrating potential uses of the cost/benefit model. Many more scenarios may be equally or more interesting to NDSF and others; use of the model is encouraged and expected. Further use of the model was in fact one of the Willis Group recommendations. However, it would be a serious mistake to concentrate only on scenario analysis without consideration of the other recommendations and caveats provided in the report.

In the following section of this report, the five scenarios will be explained. In conjunction with the scenario discussion in the Willis Group Report, and with due consideration of the other recommendations provided, this should allow a better understanding of the scenario related recommendations. A discussion of the other recommendations of the Willis Group Report also follows.

General Scenario Conditions: Every year brings a new set of cruises to NDSF operators. Cruise locations and schedules vary from year to year. For the purposes of this study, a “typical” year had to be proposed. For the ROV system, that theoretical typical year was composed of:

- 1 mid-ocean cruise. 4 day mobilization, 5 day transit, 20 days on station, 4 day transit, 2 day de-mobilization
- 1 observatory service cruise.   4 day mobilization, three legs of
    - 1 day transit
    - 8 days on station
    - 1 day transit
    - 1 day in port on first two legs

  2 day demobilization
- 2 "typical" cruises. 4 day mobilization, 1 day transit, 12 days on station, 3 day transit, 2 day demobilization

Note that personnel day rate costs presented in the Willis Group report, and in the spreadsheet available for distribution are representative costs obtained by surveying several comparable academic vehicle operators and computing the arithmetic mean of the results. This procedure was carried out to avoid open publication of actual salary numbers which are considered private. Analysis of the individual numbers and of the mean convinced the Willis Group that using this mean as an assumption did not significantly affect the results and was less significant than many other assumptions and conditions made in the report.

Scenario 1: – ROV Data Processor; Employee. The Jason ROV operational team typically includes 9 watch standers and a Data Manager. One of the functions of the Data Manager is to perform data processing tasks. Many of these tasks involve operation of existing software tools to move data between collection and processing/archiving systems and to perform standard numerical manipulations on the data. The most interesting and intellectually demanding of these routine tasks is so-called renavigation, in which real time navigation estimates are replaced by (hopefully) improved estimates prepared by combining high and low frequency fix sources using algorithms and information not available in real time. On some missions, the ROV conducts multi-beam mapping, requiring significant "hands-on" attention of the data processor, tweaking and adjusting sensor and timing parameters to produce an accurate sea floor map.

By increasing the bandwidth available for ship-to-shore communications, it would be possible to send some of the ROV data ashore where a WHOI employee, working only part time on this task, could process it as necessary and return the results to the ship.   (During the preparation of this report, a WHOI engineer working from a coffee shop in Colorado processed and returned navigation data from a Jason dive performed off the coast of California, using data transferred during a test of the R/V Sally Ride's satellite system). This does not replace all of the Data Manager's at-sea tasking (they are also involved in physical preparation of data products at sea, and in a variety of generally IT-related tasks). However, the working assumption of this scenario is that if the data-processing aspects of the Data Manager's responsibilities were moved ashore, then other at-sea team members could carry out the rest of their tasks.

If this assumption is accepted, there are cost implications on several fronts:

- The Data Managers salary costs could be removed from cruise costs for the entire period of the cruise, including the mobilization and any transit periods. In this scenario, the Data Manager is assumed to be a WHOI employee. Personnel ashore would have to charge salary to carry out the data processing tasks, but routine data processing is not a full time job, and they would charge less than 8 hours per day. These shore side processing costs would only have to be added to the real cost of the cruise on the days that the work had to be performed, which would only be on days that vehicle diving occurred.

- Removal of the Data Manager from the operational team means that one less person is available during the mobilization. This would reduce the manpower available for the wealth of purely physical tasks involved in mobilization on a new vessel. Since the Data Manager is nearly always an individual with IT skills, they would also be significantly missed in connecting the host vessel IT infrastructure (*e.g.* two way navigation flow, Dynamic Positioning system control, video channels, and network connections) to the portable ROV system. Furthermore, since the working assumption of this scenario is that satellite bandwidth is being increased, and made available to the ROV system, there could well be additional configuration work necessary during the mobilization. Therefore, this scenario includes travel and salary costs associated with augmentation of the mobilization team with an IT/networking expert who will also help with general mobilization tasks.
- It is assumed that some expenditures on capital equipment (*e.g.*, a network router more sophisticated than that currently in use) and on training for the new systems would have to take place; these costs are included in the model.

There are several difficult to quantify factors in this scenario:

- At times, ROV data processing operations are carried out immediately after a dive concludes, no matter whether the dive ended during “normal” working hours or not. Personnel at sea are expected to be available 24/7. It is not clear how this type of operation would be carried out ashore, where personnel do not expect to routinely work on weekends or holidays, or during non-work-day periods. There are cruise/dive situations when the planning for one dive requires immediate products from a previous dive, or sometimes that interim data processing products be produced while a “previous” dive is still ongoing. This sometimes drives the immediacy of data processing at sea. The Willis Group report discusses several methods for setting up compensation models for supporting shore-side support of these kinds of needs (and accommodates overtime pay), but current WHOI systems do not allow for such variations. It would be possible to utilize contractors for performing the processing; this bypasses administrative system hurdles while potentially adding cost and complexity. In the analysis of the model provided, “straight-time” estimates were used, with no overtime or comp-time assumptions. In the long run, this is not a realistic approach.
- Despite the high reliability and best efforts of the HiSeasNet and ship support systems, there are inevitably periods when ship-shore satellite communications become unavailable. This is occasionally due to equipment failures. It is more often due to the practical necessity that the host vessel be on a poor heading for satellite communications,

usually due to ship structures blocking the line of sight to a geostationary satellite. This situation usually occurs during transit periods, when the vessel must follow a particular course. However, due to prevailing winds and seas, it also sometimes occurs during ROV operations. This situation prevents data transfers, making routine processing unavailable. Although it would almost always be possible to "catch up," deep submergence science as we have come to expect it would be affected. The cost of this effect on science is difficult to quantify, and it is not represented in the scenario. This and other difficult to quantify costs and benefits *can* be represented in the Willis Group financial model, but due to the significant uncertainty in generating a dollar value, this capability was not used in any of the scenarios.

- Other than the Expedition Leader, the Data Manager is typically the member of the Jason team that interacts most frequently with the science party. This interaction is important. Removal of the Data Manager from the at-sea team could decrease Science-NDSF personal contact and thus presents an important challenge to overcome. As a society, we have come to accept teleconferencing as a partial substitute for face to face contact, and we use it routinely to save travel costs and time. If bandwidth is available, teleconferencing could aid in Science/NDSF communications. However, any reduction in the effectiveness of communications between the Science Party and the NDSF team is not represented in the model.
- The Data Manager is a part of the Jason ROV team, and does more than Data Management. Typically, all members of the team help out on deck during vehicle launch and recovery operations, and contribute according to their expertise in many ways. Removal of any one person from the team diminishes the "surge" capability of the team and potentially affects the ability of the team to solve unanticipated problems. Furthermore, only the data processing function of the Data Manager is being filled by the shore side personnel—the other aspects of their job will have to be carried out by the other members of the team. This will increase the workload and stress of the at-sea team. This effect is also difficult to quantify and it is not represented in the model.

Scenario 2: – ROV Data Processor; Contractor. This scenario is identical to Scenario 1, with only one exception: the at-sea Data Manager being replaced is considered to be an independent contractor instead of a WHOI employee. The shore side data processing task is still assumed to be performed by WHOI employees. The primary effect of this change is monetary; all other issues remain the same.

Scenario 3: – Alvin Data Processing. The HOV Alvin, permanently hosted aboard R/V Atlantis, normally includes 8 personnel in its at-sea team. These personnel are divided into electrical and mechanical teams; together with ship's crew members they routinely carry out the operations necessary to safely carry two scientific observers to the sea floor and back. None of the current Alvin Group jobs are considered candidates for replacement by personnel ashore.

One task that has historically not been performed in the Alvin at-sea operations is routine data processing like that described in Scenario 1 for ROV operations. The Alvin group has never routinely included a data processor or manager. Scientific pressures to do so arise whenever a scientific mission requires post-processed navigation or mapping related data. This scenario was introduced to evaluate the cost of increasing satellite bandwidth and providing Alvin-related data processing functions ashore.

Just as the ROV data processing required assumptions about the ROV operational schedules, so too does the Alvin scenario. The prototypical year for Alvin calculations includes:

- One mid-ocean cruise, including 4 days of transit, 26 days on station, and 5 days transit
- Two "typical" cruises, including 2 days of transit, 16 days on station, and 2 days transit

Shore side Alvin data processing, requiring 4 hours per day, was assumed to be performed by WHOI personnel only on dive days, although the satellite bandwidth was increased for the entire at-sea period.

Note that there is *no* counterbalancing reduction in costs due to leaving personnel ashore, since this scenario is intended to evaluate an increase in capability and service provided by NDSF as a result of employing satellite based telecommunications.

Because there is no reduction in costs due to supplanting of at-sea personnel, this scenario is also relevant to the AUV component of the NDSF. As the Willis Group report explains, AUV Sentry staffing is typically driven by on deck requirements, and Sentry management is unwilling to reduce it. However, should additional processing requirements be imposed on the Sentry team, this scenario offers an example of how to use the model to assess the costs of meeting this need through telepresence. In this case, it would be necessary to adjust the "prototypical year" to match Sentry schedules.

Scenario 4: ROV; Leave Engineer Ashore. As stated earlier, the Jason ROV team typically brings ten team members to sea. Three of these stand an engineering watch in the Jason control van, operating the deep sea winch and generally assisting the pilot and operational team by monitoring the variety of complex systems involved in operating the vehicle and shipboard equipment. At times of high pilot workload, they occasionally operate one of the ROV's two manipulators or otherwise assist the pilot. Despite the variety of duties, this is frequently not a very busy watch position, leading to occasional pressure to leave one or more of the "engineers" ashore. This scenario envisions just that: leaving one of the engineers ashore and utilizing satellite telecommunications to allow engineers ashore to share in non-watch standing tasks, including troubleshooting, as needed. A very limited amount of interaction with engineers ashore was postulated, as discussed in the Willis Group report.

Note that many of the concerns expressed in Scenario 1 concerning availability of personnel at sea, surge capability, and the effects of a reduction of at sea manning on critical operations also apply to this scenario. Occasionally, in all ROV systems, operational events and equipment malfunctions require hands-on troubleshooting and repair from every available resource. Although personnel ashore can and do help in troubleshooting and can provide answers and advice, they cannot turn wrenches or solder electronic connections. Reducing the number of personnel at sea carries the risk of increasing repair times when equipment needs repair. This cost is difficult to quantify and is not represented in the model.

In recognition of the potential effect on critical at-sea personnel during certain types of cruises, the hypothetical cruise plan was used in a different way for this scenario. One of the “typical” cruises was meant to represent an observatory service effort. Experience shows that these cruises are very demanding on at sea engineering. Leaving an engineer ashore is least palatable on this type of cruise, so this scenario postulates full manpower during the observatory service portion of the yearly schedule.

One possibility that has been raised many times is that personnel ashore could assist in carrying out the pre and post dive checkouts that accompany every dive, relieving the at-sea personnel of this burden. Analyses did not really consider this possibility, since current procedures require participation of personnel both in the ROV control van and on deck for safety reasons. Since the procedure already requires two team members, although personnel ashore could certainly assist (provided some new software was developed) they could not supplant the roles of those at sea, so would not offer cost savings.

Again, similar to Scenario 1, the engineer being left ashore fills important tasks during mobilization, and the scenario allows for this by providing travel and salary costs for an additional engineer to help during mobilization.

Scenario 5: ROV Data Processor; Employee, with monitoring. One of the operational uses of telecommunications/telepresence explained in the Willis Group report is providing situational awareness for management and other personnel ashore. This requires an increase in satellite bandwidth over the other scenarios, as well as a larger capital expenditure to provide some amount of on-board camera systems and other monitoring tools. An existing scenario with seemingly high potential benefit (Scenario 1) was chosen, and additional bandwidth and some capital costs for monitoring equipment procurement and support were added. All of the additional considerations of Scenario 1 continue to apply.

There are some non-quantified benefits of this scenario. For example, imagery from on-board camera systems (and from the ROV) could provide not only situational awareness to managers but also provide outreach capabilities to a much broader audience. This is not really an operational benefit to NDSF, but is potentially a positive factor in helping NDSF and its sponsors prove their societal impact and relevance.

It is also difficult to quantify the value of situational awareness for personnel ashore. Since it is rarely available under current operating conditions, making the argument that it is a requirement is difficult. However, reports from a recent NDSF cruise performing a forensic investigation of a high-profile shipwreck, during which situational awareness tools were available, claimed that the provision of these capabilities was vital in performing the investigation and despite its cost, pointed it out as a cruise highlight.

Discussion of Scenario-Based Recommendations: The Willis Group report presents a range of recommendations based upon cost/benefit analysis of the scenarios just discussed. All of these were based upon conservative financial assumptions, including interest rates, operating cost inflation assumptions, and the representativeness of the salary and other costs used. The acceptability of the recommendations is wholly subject to the reasonableness of these assumptions.

Part of the guidance that WHOI/NDSF gave the Willis Group was that berth space was a vital concern to UNOLS and to the funding agencies. By assessing the cost of implementing telecommunications strategies to reduce NDSF berth space requirements, and assuming that berth space on NDSF cruises is always oversubscribed, it becomes possible to calculate a value for a shipboard berth at which the attendant costs of the implementation will pay for themselves in a given number of years. All of the qualifiers presented in the scenario discussions *must* be considered when performing this kind of assessment. Losing a day of science time because the personnel necessary to quickly fix equipment problems were left ashore may obviate the value of any berth freed up for science use.

Scenarios 4 and 5 both imply the existence of infrastructure whose cost is not necessarily accounted for in the financial analysis. In its section on Instrumentation Support (2.2.1), the Willis Report described how the Ocean Observatory Initiative Coastal and Global Scale Node (OOI CGSN) system supports a widespread at-sea network of highly sophisticated buoys and moorings almost entirely through telecommunications. It also makes the point that these are integrated systems, designed from the start for telecommunications support, and they are supported by a large organization of full time engineers, technicians, and managers. While effective NDSF use of telecommunications for engineering support and situational awareness does not require this level of financial and institutional commitment, it does require more than just an Internet connection. Detailed examination of the report's findings on applications and use cases and more detailed requirements analyses are necessary before implementation of these recommendations.

Continuing the OOI analogy, the CGSN moorings were designed from conception to be supported via limited bandwidth telecommunications. As new vehicles are designed for scientific use, if they were designed for maintenance and support using automation and remote assistance, their use might allow reduction of the uncertainties related to equipment failure and troubleshooting, and significant reduction of at-sea personnel needs.

Expanding on this thought, all of the scenarios analyzed consider relatively straightforward transfer of roles from ship to shore, retaining the existing NDSF organizational structure and operational patterns. A broader system level look at functions and roles within NDSF might reveal new ways of staffing and operating the vehicles, breaking traditional operational roles and looking for ways to incorporate new technology and telecommunications capabilities from the outset, instead of as "add-ons".

The scenarios presented do not consider other potential functions of personnel ashore made possible by the bandwidth provided to address the particular scenarios. For example, should software development by experts ashore be necessary for any reason, any of the scenarios presented would provide the bandwidth necessary for immediate software assistance from ashore. This would not displace at sea personnel but would provide new potential resources not otherwise available.

Other Recommendations: The Willis Group made a variety of other key recommendations, some of which are summarized below. Consideration of these recommendations is vital if the scenarios presented and any other scenario that might be postulated are to be successful. The first of these is welcome, since it provides some assurance that the fundamentals of HiSeasNet are sound:

- **No Modification to Current Shipboard Telecommunications Systems:** The current systems deployed on UNOLS vessels are completely capable of supporting the functions, applications and use cases presented in the report. The basic transport mechanism from ship to shore and return needs no major capital investment.

Despite the efficacy of the ship to shore communications link, all of us who have tried to use the Internet from sea are familiar with the conditions that drive the Willis Group's other recommendations. Our collective appetite for bandwidth is insatiable and unconstrained use of it (including the ill-disciplined tendency of our personal computer systems to continually update themselves and access Cloud resources) threatens any attempt to use high bandwidth ship to shore communications for routine functions. The utility of internet connectivity varies widely between UNOLS vessels and even between cruises, making it an unreliable asset whose issues are poorly understood by its users. These concerns drove other recommendations:

- **Bandwidth Usage Policy:** Shipboard bandwidth will be a scarce resource for the foreseeable future. The scenario-based recommendations would be pointless on some UNOLS vessels without effective allocation and protection of the satellite bandwidth necessary to get data ashore.
- **Evaluation and Documentation of Shipboard Telecommunications Technology and Data Networks:** The independent nature of research vessel operations and operators means that the way in which NDSF assets (as well as any other scientific or engineering teams trying to effectively use bandwidth) interface to the Internet from shipboard varies between vessels. In some cases, the vehicle network has had direct connections to the router and firewall system first in line after the shipboard modem. In other cases, the NDSF network is a subnet connected to a shipboard science network shared with all other ship and science needs. These variations complicate supporting vehicle operations from shore.

These recommendations are based upon primarily anecdotal evidence provided to the Willis Group during interviews. Many interviewees expressed strong concerns about the feasibility of implementing effective use of telecommunications given their frequently poor experience with shipboard Internet connectivity. Shipboard telecommunications and connections to the shipboard systems may need to be standardized in the same way that deck sockets and other methods of using shipboard systems for scientific uses have been. This would cause some loss of control and independence on the part of the vessel operators in exchange for more efficient and capable science operations.

- **Personnel Related Recommendations:** While the Willis Report did not recommend routine addition of a shipboard satellite technician, it did acknowledge that in the event a cruise was supporting both scientific telepresence and operational use of telecommunications an onboard specialist would be appropriate. Furthermore, it recommended a feasibility study of establishment of a shore side technical operations resource pool. While the specific recommendation concerning the technical operations resource pool appears related to vehicle operations, it may be even more appropriate for technical assistance as applied to telepresence and telecommunications support.

Here is where real synergy with the scientific use of telepresence appears. Scientific telepresence requires more bandwidth than the engineering support described in the Willis Report, but otherwise, most of its other technical aspects are extremely similar. Each use of telecommunications strengthens the other; the synergy does not necessarily add significant cost to either when considered alone.

Summary

This report describes the completion of a study by the Willis Group evaluating the potential of modern telecommunication and telepresence systems to help the National Deep Submergence Facility in the performance of their missions.

The study concluded that the current satellite telecommunications infrastructure aboard UNOLS vessels is sufficient to allow cost effective use of resources ashore to augment and/or replace personnel at sea. A set of WHOI-provided scenarios, evaluated over “typical” operational schedules were used to reach this conclusion and to illustrate several ways in which this augmentation or replacement could be effected. The resulting recommendations are based upon a set of important assumptions and preconditions, as well as upon the recognition that a variety of non-quantifiable costs and benefits would accompany any change in operational approaches.

When considered along with scientific uses of telepresence that extend the *user* base ashore, the Willis Group report (attached as an Appendix) provides evidence that continued investment in technology and in satellite bandwidth provides strong return in science/dollar. The cost benefit model that accompanies the Willis Report provides a powerful means to evaluate the quantifiable portions of that return.

Appendix A:

NDSF Technical Operations via Telecommunications

A report prepared by The Willis Consulting Group for the Woods Hole Oceanographic Institution

WOODS HOLE OCEANOGRAPHIC INSTITUTION

NDSF Technical Operations via Telecommunications

Applications and Technology Evaluations
&
Cost Benefit Analyses

prepared by:

Willis Group

24 October, 2017

Revision 1.0

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Executive Summary

This study evaluates the potential for reducing NDSF (National Deep Submergence Facility) shipboard personnel required to support multiple categories of shipboard technical operations tasks, by instead performing some of those tasks from ashore – a process referred to as 'technical operations via telecommunications'. One of the catalysts for this evaluation is the deployment of Ocean Class vessels, and associated concerns about accommodating reduced berth space, compared to Global Class vessels.

Summary

A discovery process identified operational requirements associated with performing some NDSF shipboard technical operations functions with shoreside personnel. Seven candidate applications were identified to fulfill those requirements, which in-turn led to defining use-cases based on operational processes, along with associated enabling technologies.

Cost / benefit analyses evaluate financial impacts of five scenarios based on implementing shoreside technical operations via telecommunications. Costs for shipboard technical support operations are compared with costs associated with performing those technical operations with shoreside personnel via telecommunications networking.

A key variable in analyzing four of the five scenarios is the value of a shipboard berth. Quantifying a berth value, however, proved difficult. Rather, for these four scenarios, breakeven analysis is employed to quantify a value to achieve neutral net cost, or net cost savings.

One scenario shows a net benefit with a $0 berth valuation. Two scenarios achieve breakeven within three years based on berth valuations of less than $150 per day. Additional bandwidth costs associated with one scenario result in a breakeven value of $1,200 per day. See Section 6.2.5, Scenarios, page 65; Section 6.2.6, Scenario Analyses and Interpretations, page 75; and Multiple Year Breakeven Per-Day Berth Valuations, page 79.

A fifth scenario differs significantly from the four noted above, as it evaluates adding data processing utilizing shoreside personnel, without displacing any current shipboard operations. This scenario, therefore, quantifies costs for adding data processing functionality not currently supported shipboard. See Scenario 3 – HOV with Data Ashore, page 70.

Conclusions and Recommendations

Cost / benefit evaluations of utilizing shoreside personnel to perform tasks normally executed by NDSF shipboard technicians / engineers, conclude that multiple scenarios yield net benefits.

Scenarios typically involve modifying operational workflow processes, potentially introducing largely non-quantifiable benefits and/or risks. See Section 6.2.4, Benefits and Risks, page 63.

All evaluations in this study are based on conservative financial assumptions, ignoring potential benefits from synergies, economies of scale and/or non-quantifiable benefits, leading to conservative results, which might otherwise be more favorable. See Bandwidth Synergies / Economies of Scale, page 76, as well as Non-Quantifiable Benefits, page 64. Non-quantifiable operational risks also do not factor into objective financial analyses, and are instead considered as part of subjective scenario analyses. See Risks and Potential Disadvantages, page 65.

Recommendations and associated rationales for each of the five scenarios evaluated for this study, as well as guidance for implementing policies / procedures, personnel staffing considerations and technology options, are detailed in Section 6.3, beginning on page 82, and are outlined below.

- Scenarios with net neutral cost or net cost savings are unconditionally recommended for implementation. See Scenario 2, page 83.

- Implementing technical operations via telecommunications is recommended for two scenarios with breakeven per day berth valuations of less than $150 per day. See Scenarios 1 and 4, page 83.
- A higher breakeven per day berth valuation of $1,170 leads to a qualified recommendation to implement technical operations via telecommunications in scenario 5, only for circumstances where berth scarcity prevails. See Scenario 5, page 83.
- One scenario is based on adding shoreside data processing, with no associated shipboard cost savings. Viability of this scenario is dependent upon perceived benefits of shoreside data processing being equal to or greater than associated costs. See Scenario 3, page 84.
- Three separate recommendations advocate establishing policies and operating procedures:
  - Shipboard – Bandwidth Usage Policy, page 84.
  - Shipboard – Initiate Satellite Network Connection During Mobilization, page 84.
  - Shoreside – Full End-to-End Facilities Check During Mobilization, page 85.
- Personnel staffing considerations lead to three recommendations:
  - Adding a shipboard satellite technician is discouraged for technical operations, while acknowledging it may be appropriate for science via telepresence; see Shipboard – Satellite Communications Specialist, page 85.
  - Designating shoreside IT administrators is recommended; see Shoreside – IT Administration, page 86.
  - A feasibility study is recommended for establishing a technical operations resource pool; see Shoreside – On-Demand Distributed Tech Ops Resource Pool, page 86.
- Five recommendations focus on technology options:
  - No modification to shipboard satellite systems is recommended. See Leverage Existing Science via Telepresence Satellite Communications, page 86.
  - Evaluations of shipboard and shoreside technology systems are recommended.
    - Evaluate and Document Shipboard Telecommunications Technology, page 87.
    - Evaluate and Document Existing Shipboard Data Networks, page 87.
    - Evaluate Shoreside Data Network, page 88.
  - Shipboard technology standardization is recommended. See Standardize Shipboard Technology Infrastructure, page 87.
- Five scenarios were evaluated for this study. Modifying assumptions in these five scenarios to better match unique conditions, and/or evaluating additional scenarios utilizing the accompanying Excel® model is encouraged. See Evaluate Additional Scenarios, page 88.

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1 Project Overview

Deployment of Ocean Class vessels, and associated concerns about accommodating reduced berth space, compared to Global Class vessels, led WHOI (Woods Hole Oceanographic Institution) to commission this study to evaluate the viability of 'technical operations via telecommunications'. This study evaluates the potential for reducing NDSF (National Deep Submergence Facility) shipboard personnel headcount required to support multiple categories of shipboard technical operations tasks, by instead performing some of those tasks from ashore.

1.1 Scope of Work

This evaluation is based on a multi-phase process, beginning with discovery, to define operational requirements. Candidate applications are then identified to fulfill those requirements, which in-turn lead to defining use-cases based on operational processes and technologies to enable those applications. Cost / benefit analyses evaluate financial impacts of each candidate application. Recommendations are then proffered.

1.1.1 Discovery and Requirements Evaluation

Guided by WHOI, this study includes a review of existing documents, interviews with key personnel and observations of some relevant operations. Associated analyses were then performed to ascertain requirements of expedition operations using ROV (Remotely Operated Vehicle), AUV (Autonomous Underwater Vehicle), HOV (Human Occupied Vehicle) and/or other vehicle systems.

Documentation and interviews include insights from personnel associated with multiple institutions, including WHOI, UNOLS, NSF (National Science Foundation), NOAA (National Oceanic and Atmospheric Administration), NOC (National Oceanography Centre), ISC (Inner Space Center), UCSD / HSN (University of California at San Diego / HighSeasNet), GEOMAR and UH (University of Hawaii).

1.1.2 Technical Operations via Telecommunications Applications

This study focuses on evaluating costs / benefits associated with performing and/or supporting shipboard technical operations via telecommunications. It is viewed as complementary to science via telepresence. Please note that some in the oceanographic research community refer to technical operations via telecommunications as *datapresence*.

When identifying a scope of work for this study, it was thought technical operations via telecommunications applications would differ significantly across vehicle types; ROV, AUV, HOV. Mission objectives are frequently correlated with vehicle type, but not always, leading to inclusion of mission type as a further consideration when identifying candidate applications.

A noteworthy observation from this study is that shipboard technology platforms are not standardized. Shipboard technology platform, therefore, is another variable accounted for when considering candidate applications.

Evaluations begin with identifying practicable candidate applications for technical operations via telecommunications. Operational scenarios are described, and use-cases are developed for applications common to multiple vehicle types, as well as those that apply exclusively to an individual vehicle type. Where appropriate, scenarios and use-cases reference shipboard technology platform considerations, as they relate to operational requirements.

1.1.3 Personnel Considerations

A key intended goal of this study is to evaluate the potential for reducing shipboard headcount necessary for NDSF vehicle operation, thereby freeing up bunks to be available for a larger science party. To ascertain this potential, personnel skills, workday schedules and other operational variables are evaluated.

A significant finding from this study is how expectations for shipboard workdays differ from shoreside workdays. This is a key factor in cost / benefit evaluations of deploying candidate applications.

1.1.4 Telecommunications Technology Requirements

After identifying candidate applications, the next step is to evaluate technology requirements to enable them. The scope for this project is to provide technology concepts, with more details to be developed separately, should WHOI and/or its partners choose to pursue a follow-on project.

The study reveals differing requirements among vehicle and/or mission types, but there are also many commonalities. Common applications are sometimes based on similar shipboard technology platforms, e.g. communications infrastructure, and sometimes on vehicle-specific and/or mission-specific operations.

1.1.5 Cost / Benefit Analyses

All of the scope of work described in subsections 1.1.1 through 1.1.4 above is intended to inform cost / benefit analyses. These analyses are performed for multiple scenarios, based on candidate applications.

1.1.6 Recommendations

Cost / benefit analyses for each candidate application are valuable references when choosing whether or not to deploy a given candidate application. Making choices based on financial analyses alone, however, may be misleading. While still relying heavily on financial cost / benefit analyses, recommendations provide a more balanced consideration of options.

1.2 Methodology

A discovery process was initiated in collaboration with WHOI Principal Investigator, Jonathan Howland. Relevant documentation was supplied, and key personnel were identified for interviewing. References in some supplied documents led to discovery of additional documentation, and interviewees revealed further relevant resources.

Information gleaned from document reviews and interviews with key personnel leads to identifying several candidate applications. Independent research then helps to define operations workflow and technologies to enable these applications.

Several use-cases are then detailed to help make some operations and technology concepts more tangible. Use-cases address operations and/or technology considerations associated with mission-type and/or vehicle type – ROV, AUV, HOV.

Implementation and operating costs, as well as operational cost savings – especially shipboard personnel headcount reduction – are then estimated, leading to comparing baseline costs with each of multiple scenarios that are based on practicable applications identified in this study. Quantifiable benefits are then summed with comparative cost results to arrive at an overall net cost / benefit.

1.2.1 Documentation Review

Documentation supplied from WHOI, plus documentation revealed during discovery include:

- UNOLS schedules
- Jason / Medea pre and post dive checklists
- Sentry Operations Report for the EX1205 Cruise - NOAA Ship Okeanos Explorer – July 5, 2012 to July 24, 2012 (July 24, 2012)
- EX 1205 Leg I, Exploration of Blake Ridge with NDSF Sentry AUV; Expedition Assessment: Perspectives from shoreside team (July 5-24, 2012)
- EX1205 LEG 1: Blake Ridge Exploration, Lessons Learned – Kelley Elliott (2013)
- Telepresence field research experience for undergraduate and graduate students: An R/V Okeanos Explorer/AUV Sentry success story – Authors: Van Dover, C. L. ; German, C. R. ; Yoerger, D. R. ; Kaiser, C. L. ; Brothers, L. (December, 2012)
- Satellite Based Remote Management and Operation of a 6000m AUV; Carl L Kaiser, James C Kinsey, Webb Pinner, Dana R. Yoerger, Christopher R German, Cindy Lee Van Dover (*Oceans*, Hampton Roads, VA, 2012, pp. 1-7)
- NSF publication – Sea Change: 2015-2025 Decadal Survey of Ocean Sciences – THE NATIONAL ACADEMIES PRESS, Washington, D.C. (Copyright 2015 by the National Academy of Sciences)
- UNOLS Telepresence Guidance for Scientists and Ship Operators; Dwight Coleman, Webb Pinner, Kevin Walsh, Alice Doyle (February 16, 2016)
- UNOLS Regional Class Research Vessels, RCRV Datapresence Survey Draft Report, Chris Romsos, Jasmine Nahorniak – OSU, (October, 2015)

1.2.2 Interviews with Key Personnel

Key personnel were interviewed on-site, via email and/or via telephone. Some interviewees were identified by WHOI, while others were referrals from those initial interviewees. Table 1 below lists each interviewee, along with his/her institutional affiliation. Many thanks to all who freely shared their insights.

Interviewee	Affiliation	Interviewee	Affiliation
Jon Alberts	UNOLS	Akel Kevis-Stirling	WHOI
Rita Bauer	UCSD / HSN	Robert Knott	ISC
Andy Bowen	WHOI	Tom Kwasnitschka	GEOMAR
Dwight Coleman	ISC	Elizabeth ‘Meme’ Lobecker	NOAA
Alberto 'Tito' Collasius	WHOI	Mashkoor Malik	NOAA
Stephen Damas	ISC	Catalina Martinez	NOAA
Annette DeSilva	UNOLS	Scott McCue	WHOI
Alice Doyle	UNOLS	Brian Midson	NSF
Chris German	WHOI	Cathy Offinger	WHOI
Matt Heintz	WHOI	Bruce Strickrott	WHOI
Jonathan Howland	WHOI	Anthony Tarantino	WHOI
Julia 'Jules' Hummon	UH	David Turner	NOC
Carl Kaiser	WHOI	Korey Verhein	WHOI
Brian Kennedy	NOAA	Kevin Walsh	UCSD / HSN

Table 1 Interviewee List

1.2.3 Follow-up Research and Analyses

Some candidate applications identified through discovery, research and analyses revealed prior art with a potential to inform operations workflow and/or technology systems. For those applications with no discoverable prior art, workflow and technology systems options are developed and presented.

Financial cost / benefit analyses are performed for each candidate application, which are key considerations when evaluating deployment options.

1.2.4 Recommendations

Evaluating options and making associated recommendations is based on synthesizing operational, technical and financial information.

1.3 Organization of This Document

In addition to this Project Overview, there are six sections in this report:

- An Executive Summary, at the beginning of this report, summarizes key findings about utilizing telecommunications to support shipboard technical operations, including operational and financial analyses, as well as recommendations for workflow processes, configuring existing technology systems and/or deploying new technologies. References to more detail in the body of this report are provided.
- Section 2, Technical Operations Applications Assessment, beginning on page 6, identifies potential applications across all vehicle types. Each identified application includes a description of operational workflow processes and technology requirements to enable those processes.
- Section 3, Technical Operations – Use Cases, beginning on page 14, describes specific situations that incorporate applications identified in Section 2. These descriptions include operational workflow processes.
- Section 4, Personnel Considerations, beginning on page 24, addresses staffing considerations associated with technical operations via telecommunications, and use-cases described in Sections 2 and 3, respectively.
- Section 5, Technology Options, beginning on page 32, offers technology systems concepts, designed to enable skilled personnel identified in Section 4 to perform operations described in Section 3.
- Section 6, Analysis and Recommendations, beginning on page 50, presents multi-year cost / benefit analyses of candidate applications and use-cases described in Sections 2 and 3, integrating personnel considerations described in Section 4, and as enabled by technology systems described in Section 5. These comparative analyses lead to recommendations with associated rationales.

Acronyms

An Acronym Glossary is included at the end of this report for reader convenience. The convention for acronym usage is to fully define it upon first usage, and then use only the acronym from that point forward.

Navigation

References to other sections / subsections / pages included throughout this report are intended to provide the reader with a convenient means for navigating to relevant explanatory information. If reading this as an electronic document, all of these references are active hyperlinks.

1.4 About the Key Personnel

1.4.1 Willis Peligian – Principal Author and Consultant

As owner and principle consultant of WCG (Willis Consulting Group) for the past twenty-five years, Willis provides strategic business, technology and operations consulting services to scientific research organizations, universities, the media & entertainment industry, among others who utilize rich media – video, audio, data, metadata. He assists clients with defining business requirements, operations workflow plans, technical facilities designs, cost/benefit analyses, among other assignments.

Oceanographic telepresence projects include: strategic planning and telepresence system design for the Lost City Expedition (2005); USNS Capable conversion to R/V Okeanos Explorer, including shipboard telepresence system designs; and strategic planning, operations and technology system designs for ISC (Inner Space Center).

1.4.2 Jonathan Howland – co-Principal Investigator

Jonathan Howland is a Senior Engineer in the Applied Ocean Physics and Engineering Department at WHOI. He has been a member of the Deep Submergence Laboratory and the National Deep Submergence Facility since 1990.

Jon's work focuses on underwater vehicle design and control, navigation, imaging and software. He has participated in more than 50 research and engineering cruises during that time, many of which have incorporated telepresence and telecommunications.

1.4.3 Adam Soule – co-Principal Investigator

Adam Soule currently serves as the Chief Scientist for Deep Submergence at WHOI, a position he has held since 2014. He is an Associate Scientist in the Geology & Geophysics Department, and his research focuses on volcanic processes in the ocean basins and associated tectonism, hydrothermal circulation, and biologic colonization.

Adam has participated in 20 research cruises over the past decade, using a variety of deep submergence vehicles including: HOVs Alvin and Nautile; ROVs Jason, Hercules, and Doc Ricketts; AUVs Sentry and Remus; and a variety of towed platforms. Adam has participated in telepresence-enabled cruises both onshore and at sea.

1.5 Contact Information

For questions / comments about this report and/or the accompanying Excel® workbook, please contact Jonathan Howland, jhowland@whoi.edu, (508) 289-2653.

2 Technical Operations Applications Assessment

Evaluating costs / benefits associated with supporting shipboard technical operations from shore, begins with identifying practicable applications to fulfill requirements, as articulated by interviewees. Seven candidate applications have been identified, each of which is described in the following subsections.

Subsections 2.1 through 2.7 each address a single application, including a description of operational workflow processes as well as a brief explanation of enabling technology requirements – more detailed technology descriptions are presented in Section 5, Technology Options, beginning on page 32.

Detailed use-cases for each vehicle type are not included here, but rather are covered in Section 3, Technical Operations – Use Cases, beginning on page 14. Of particular note, differing scheduling considerations for shoreside and shipboard personnel were identified as key factors to ensure successful deployment and sustainability of technical operations via telecommunications applications. See Section 4.2, Shoreside Personnel, page 25.

2.1 Data Processing

A key application cited by interviewees for all three vehicle types is data processing. Multiple initiatives for standardizing and managing oceanographic data were revealed during discovery. One such initiative is OpenVDM (Open Vessel Data Management), a collection of programs and a web application that provide tools for vessel operators to manage data in a consistent fashion compatible with other, perhaps higher level, data management systems. Another is R2R (Rolling Deck to Repository), a comprehensive fleet-wide data management initiative focused on ships rather than vehicles, is supported by NSF, NOAA, ONR (Office of Naval Research) and SOI (Schmidt Ocean Institute).

Discovery for this evaluation revealed a draft report documenting a substantial effort to survey *datapresence* facilities across the United States academic research fleet. The resulting report [1] – published in draft form under the banners of NSF, UNOLS and OSU (Oregon State University) – summarizes significant findings from the survey.

While the term *datapresence* does not yet appear to have gained widespread usage, it does seem especially appropriate for this data processing application. OSU's College of Earth, Ocean, and Atmospheric Sciences defines datapresence as a complement to science via telepresence, especially so "that virtual participation will extend far beyond just video streaming" [2].

Four data processing operational scenarios have been identified for this analysis:

- stream data to shore in real-time
- bulk data transfer to shore
- shoreside personnel process shipboard data in situ
- pre-process data subset shipboard, to send ashore for further processing

2.1.1 Real-Time Data Streaming

Some vehicles and shipboard systems supply continuous data / video streams, potentially making that data available to stream directly to shore in real-time. Workflow process considerations and technology requirements associated with real-time data streaming are addressed below.

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[1] Chris Romsos and Jasmine Nahorniak. UNOLS Regional Class Research Vessels RCRV Datapresence Survey Draft Report (*15 October, 2015)*

[2] Oregon State University, College of Earth, Ocean, and Atmospheric Sciences website FAQ

Workflow Process Considerations

Based on experiences with real-time data streaming from ship-to-shore, interviewees recommend shipboard and shoreside watchstanding liaisons to coordinate logistics and communications. Watchstanding offers one form of situational awareness, which is identified as a significant application. See below in subsection 2.5, Situational Awareness, page 12. Also, Watchstander Liaisons, under Section 3.1.2, Mission-Specific Use Cases, page 17.

Technology Requirements

Satellite network connectivity with adequate bandwidth that is reliably sustainable during vehicle operations is required to facilitate real-time data streaming. Unreliable connections can render unworkable real-time streaming.

Shipboard satellite communications technology modifications can sometimes improve reliability. In most cases, however, satellite network reliability is a function of location. Bulk Data Transfer, described below, is recommended for situations where reliable satellite network connectivity is intermittent.

2.1.2 Bulk Data Transfer

One method for processing data is to transfer all data from ship-to-shore, where multiple shoreside personnel work in parallel. Resulting subsets of processed data can then be returned to ship, providing scientists with more timely access to crucial information, which enables making informed, timely decisions about prioritizing at-sea science activities.

This approach leverages many more people than would be feasible with inherent limitations of shipboard personnel staffing. Given large datasets, however, there is a requirement for more bandwidth than is typically provisioned in ship to/from shore satellite network communications.

Transferring data files to shore is an option if satellite network connectivity is intermittent, but has ‘broad-enough’ bandwidth when functional. Determining minimum bandwidth requirements is a function of data file sizes and how urgently shipboard personnel require processed data to be returned.

2.1.3 In Situ Processing via Telecommunications Network

A more bandwidth-efficient approach to Bulk Data Transfer described above is to leave data in shipboard systems, and allow shoreside personnel to connect to and interact with those systems via telecommunications network connections.

Results with in situ data processing would be similar to the Bulk Data Transfer model, but without the need to transfer large datasets to/from ship and shore. Depending upon requirements, shipboard computing systems might require a modest upgrade to enable in situ multiple parallel processes of typically graphics-intensive tasks.

When a ship is able to sustain reliable satellite network connections, in situ data processing is a preferable model to minimize satellite bandwidth costs. Unreliable satellite connections, however, can render unworkable in situ data processing.

Shipboard satellite communications technology modifications can sometimes improve reliability. In most cases, however, satellite network reliability is a function of location on the oceans. Bulk Data Transfer, as described above, is recommended for situations with intermittent satellite network connectivity.

2.1.4 Pre-Process Data Shipboard

A hybrid option was identified by some interviewees, and is suggested in some post-expedition reports of missions designed to evaluate using data via telepresence. This option involves partially processing data shipboard to subsample / excerpt a subset and/or consolidate data prior to transferring ashore. The result of this approach is to reduce bandwidth requirements to something less than that required for Bulk Data Transfer, but more than In Situ Processing via Telecommunications Network options described above.

Pre-processing can involve shipboard personnel manually excerpting data subsets. Interviewees also suggested this is already being done to some extent with automated processes to subsample data streams and/or datasets. Some suggested that with concentrated effort, these automated subsampling processes could be improved to achieve even greater reductions in data volume. Examples of automated data subsampling are described in Section 3.1.2, Mission-Specific Use Cases, below on page 16.

2.2 Remote IT and Instrumentation Support

Shipboard IT (information technology) technical support is a candidate application identified by many. Supporting shipboard scientific instruments, satellite communications systems and data networks, as well as addressing general shipboard end-user IT technical issues were the most frequently cited applications.

Three examples of remote technical support currently being supplied were revealed during discovery interviews:

- instrumentation configuration, operation and support
- shipboard satellite modem configuration, monitoring and support
- shipboard network configuration and end-user support

2.2.1 Instrumentation Support

Many shipboard instruments are designed with IP (Internet Protocol) interfaces that facilitate configuration, data upload / download and technical support. Some of these instruments are already managed over a telecommunications network, e.g. OOI / CGSN, and ADCP (Acoustic Doppler Current Profiler). The candidate application being proposed here is to exploit the ability for shoreside personnel to connect to and support shipboard instruments.

OOI / CGSN Platform Operation and Support

Coordinated by COL (Consortium for Ocean Leadership), OOI / CGSN is one example of unattended networked sensor platforms that collect and transmit oceanographic science data. Coastal platforms are visited twice yearly for servicing, but otherwise are managed from shore via telecommunications only.

As part of a multi-institutional effort, WHOI and OSU provide the core OOI / CGSN operational support. See www.whoi.edu/ooi_cgsn/about for a starting link to descriptions of the extensive support infrastructure.

The successful deployment and sustained operations of OOI / CGSN may serve as an example of how shipboard systems might be designed to support the Remote IT and Instrumentation Support candidate application that is the topic of this subsection.

Standardized, Well-Documented Systems

OOI / CGSN was conceived of as an integrated system, designed for unattended operation via telecommunications access. This affords a significant advantage over other applications, described herein, that rely on less well-documented and often varying shipboard system designs that have evolved and adapted over many years, instead of being originally designed for purpose.

Centralized Support and Data Management

Another advantage OOI / CGSN has over some other applications described herein is the large organization set up ashore for continual support and monitoring. A team of full time engineers, scientists, and technicians at WHOI and OSU are engaged in supporting all system operations, from building and maintaining hardware to data collection, processing, and distribution.

Outreach and Engagement

Integrated systems, ranging from web applications to custom hardware / software, facilitates public and educational outreach and engagement.

One essential difference between daily OOI / CGSN operations and the kind of support envisioned elsewhere in this report is that when deployed, the OOI / CGSN systems are entirely unmanned. WHOI and OSU shoreside personnel are supporting deployed hardware that will remain in place for months. This greatly affects the criticality and necessary latency of remote support, as well as eliminating many of the human factors considered elsewhere.

ADCP

This subsection focuses on ADCP system technical support. See ADCP Data Processing and Presentation, under 3.1.2, page 16, for ADCP operational details.

Julia ‘Jules’ Hummon operates from UH (University of Hawaii), currently providing ADCP support to multiple ships simultaneously. Jules is the only person presently assigned to provide this service. See subsection 4.2, Shoreside Personnel, page 25, for observations and cautions about consequences associated with this staffing arrangement.

Shipboard System

Shipboard computers acquire and process data from a particular instrument or instruments on a given vessel. That acquisition, along with associated processing and generation of data subsets, produce log files.

ADCP outputs are captured on such shipboard computer systems. Shoreside personnel – in this case, Jules – connect to these shipboard computers to configure, monitor, initiate transfers, and otherwise support them.

Shoreside Diagnostics and Troubleshooting

When an email with associated file attachment(s) arrives at UH, data are automatically plotted for graphical presentation, and parsed for web viewing. Data payloads are tailored for UH’s acquisition system, with the specific intent to provide information needed to diagnose technical problems. Diagnoses involve manually evaluating logs for anomalies, alerting Jules to possible issues she may then troubleshoot as warranted.

2.2.2 Satellite Communications Systems

Shipboard satellite communications technology configuration is a process that is best performed by an appropriately skilled person. One workaround for lacking such a person aboard ship is for a skilled person ashore to guide shipboard personnel. Some interviewees report this approach could be awkward, although most acknowledge it would be advantageous to have shoreside expertise available.

Remote Satellite System Configuration

Enabling shoreside skilled technical personnel to configure and maintain shipboard satellite systems is identified by interviewees as a desirable and potentially valuable application.

Standardize Shipboard Satellite Modem

Current shipboard satellite communications technology is not standardized, potentially complicating efforts to enable shoreside support. Well documented shipboard systems are essential to enable shoreside personnel to be effective.

Standardizing shipboard satellite communications systems, especially satellite modem technology, is also identified by interviewees as a key to facilitating effective and efficient remote shoreside configuration, diagnostics and support.

2.2.3 Shipboard Network Configuration and End-User Support

Network access to IT systems enables technical personnel to configure and support end users who utilize those systems. The candidate application being proposed here is to enable shoreside IT support personnel to configure shipboard networks, set-up user accounts, among other general IT support functions.

Shoreside personnel would presumably perform support functions required for any networked environment, whether shipboard or shoreside. Given IT support personnel typically connect via networked access to target systems, extending their reach to shipboard systems would seem a straightforward candidate application.

2.2.4 Limitations and Risks

Remote operations present multiple challenges. Two primary considerations – unreliable network connections, and situations requiring physical access to shipboard systems – are described below.

Unreliable Satellite Communications Network

One challenge to successful deployment of general IT support via telecommunications connections is intermittent network connectivity. Unreliable satellite network connections would present varying degrees of difficulty, depending upon the nature of support required at a given time.

While ships are typically equipped with Iridium Communications services, bandwidth capabilities are considered inadequate to serve as an effective alternate network connection to support technical operations via telecommunications.

Physical Access to Shipboard Systems

While most IT support is routinely performed via networked access, there are times when physical access to hardware is required. For these atypical situations, shipboard personnel could be directed to perform specific tasks by skilled shoreside personnel. See Collaborative Troubleshooting, below.

2.3 Collaborative Troubleshooting

Enabling shipboard personnel to collaborate with technical specialists located ashore and/or on other ships is already being done on missions provisioned for science via telepresence. Available bandwidth to facilitate video streaming intended for science can be utilized for ship to/from shore collaborations, if necessary.

2.3.1 Bi-Directional Sharing

Shipboard personnel would use video, audio, screen sharing or other means of demonstrating a given technical issue to shoreside personnel. Likewise, shoreside personnel can use similar means to demonstrate how to resolve the issue, possibly referencing a working version of whatever it is shipboard personnel are trying to repair. This bi-directional sharing is the essence of ship / shore collaboration.

An advantage of collaborative troubleshooting is better utilization / leveraging of shoreside personnel with specific expertise, as they can be available to multiple ships at sea. As with other candidate applications described in this subsection, however, caution is advised about shoreside personnel work schedules, and how expectations about their availability will differ from shipboard personnel. See Section 4.2, Shoreside Personnel, page 25.

2.4 Custom Software Development

It is common for science expeditions to encounter situations while at sea where modifying existing software could add significant value to a mission. Whether it be a minor patch, or a substantial code drop, the limiting factor is frequently gaining access to the person who is best suited to the task of modifying the specific software.

In many cases, there are few people familiar enough with the target software to make changes while ensuring the integrity of the modified application. This Custom Software Development candidate application would enable uniquely skilled personnel to be available to multiple ships.

2.4.1 Collaboration Tools

Enabling shoreside personnel to address software customization requests begins with communicating the desired modification(s). Voice, text and/or chat may be adequate to communicate between those requesting modifications, and those who would make modifications to software. In some cases, screen sharing would be useful to demonstrate a bug, shortcoming and/or a desired new feature.

Real-time network connectivity at relatively low bandwidth would be required to enable these tools during collaboration.

2.4.2 In Situ Code Modification

Software modified in situ on shipboard systems, would mimic In Situ Processing via Telecommunications Network, described above in subsection 2.1.3, page 7. Caveats about satellite network reliability noted for in situ data processing also apply here.

2.4.3 Shoreside Software Development with Code Drop

An alternative to modifying software in situ is to modify ashore, and drop code onto shipboard systems. Because this approach is an asynchronous activity, it is somewhat forgiving of unreliable satellite communication network connections.

2.5 Situational Awareness

Virtually all interviewees with any science via telepresence experience said situational awareness is a key enabler for successful remote operations. Additionally, some shoreside personnel expressed a desire to monitor shipboard activities in real-time, so they are aware of operational dynamics. This would allow them to more effectively interact with shipboard personnel, while avoiding interrupting at inopportune times.

Video, voice and data are the three media types interviewees indicate are most useful for situational awareness. That said, most expressed concern about the intrusiveness of video monitoring.

2.5.1 Video / Voice / Data

Shoreside personnel want to see activities in specific shipboard venues, talk with specific shipboard personnel and see data displays. Of particular interest for data displays is location and position information, including navigation data, latitude / longitude, depth, temperature, among others.

Shipboard personnel desire to see activities in specific venues ashore and talk with specific shoreside personnel.

2.5.2 Big Brother Effect

While shipboard personnel expressed a desire to see shoreside operations, those ashore are reluctant to have active cameras in various shoreside venues. Suggested shoreside venues to monitor for situational awareness include conference rooms, labs and offices.

Likewise, shoreside personnel expressed a desire to see shipboard operational venues, but shipboard personnel are reluctant. Suggested shipboard venues to monitor for situational awareness include multiple deck locations, control van, labs and common areas.

This Big Brother effect is a significant concern among many interviewees. For situational awareness to be successful, it would likely help to establish policies, possibly with the involvement of those who have expressed concerns. Deploying cameras both shipboard and ashore would also likely foster trust, based on a mutual agreement to monitor venues both shipboard and shoreside.

2.6 Community Outreach / Engagement / Career Development

Enabling people to interact from shore with shipboard operations has been successful in engaging multiple shoreside communities. Outreach and engagement are considered similar applications, whereas career development and/or training are thought to have more rigorous requirements.

2.6.1 Outreach and Engagement

Providing outreach to the general public as well as to specific communities has been a common use of telepresence. Enabling scientists to engage with K-12 students is a recurring and popular telepresence application.

Other communities are also identified as important. Engaging with current sponsors and policy makers, as well as reaching out to potential new sponsors, are cited by interviewees as a valuable use of telepresence. Technical operations via telecommunications might similarly prove popular for outreach and engagement.

2.6.2 Career Development

Undergraduate and graduate college students pursuing a career in oceanography have also benefited from gaining research experience through telepresence that would otherwise be unavailable, due to limited opportunities for going to sea. Enabling participation through telepresence provides cost-effective field research experience and career development opportunities for the next generation of oceanographic science and technical personnel [3].

When asked about technical operations specifically, interviewees largely agree that telepresence has been a valuable tool for engaging those interested in and/or pursuing a career in supporting oceanographic operations. Using telecommunications connections to facilitate direct involvement of shoreside personnel in shipboard technical operations, therefore, is identified as a potentially cost effective approach for career development.

2.7 Productivity Application Access

A common request among most interviewees is for familiar productivity tools used daily ashore, to be available shipboard. Productivity tools commonly mentioned among interviewees include:

- email
- IM (Instant Messaging), SMS (Short Messaging Service) / texting
- team logistics / coordination – Basecamp, Slack, Teamwork, Asana, et al
- message boards
- virtual meetings – WebEx, GoToMeeting, Skype, JoinMe, et al
- screen sharing
- automatic check-ins
- to-do lists
- cloud storage
- centralized schedule

Accessing commonly used applications is typically constrained by limited shipboard bandwidth. Interviewees who routinely are prevented from shipboard access to everyday productivity applications were openly envious of those who go to sea with enough bandwidth to allow access.

See Section 3.7, Productivity Application Access, page 22, for additional details.

2.8 Watchstanding and Piloting Vehicles

Two candidate applications – shoreside watchstanding, and piloting vehicles from shore – were considered, but ultimately dismissed because they were considered premature for current implementation. That said, both can be revisited in future, if/when capabilities mature.

See Section 3.8, Watchstanding and Piloting Vehicles, beginning on page 22, for additional details.

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[3] Van Dover, C. L.; German, C. R.; Yoerger, D. R.; Kaiser, C. L.; Brothers, L. An R/V Okeanos Explorer/AUV Sentry success story (December, 2012)

3 Technical Operations – Use Cases

Building on candidate applications identified in Section 2, the following subsections describe vehicle and mission-specific use-cases. Personnel Considerations are addressed in Section 4, beginning on page 24. Supporting technologies are presented in Section 5, Technology Options, beginning on page 32.

3.1 Data Processing

Section 2.1, Data Processing, beginning on page 6, describes four variations of data processing applications to support real-time data streams, and large datasets:

- Real-Time Data Streaming, Section 2.1.1, page 6
- Large Datasets:
  - Bulk Data Transfer, Section 2.1.2, page 7
  - In Situ Processing via Telecommunications Network, Section 2.1.3, page 7
  - Pre-Process Data Shipboard, Section 2.1.4, page 8

3.1.1 Vehicle-Specific Use Cases

ROV

Data, metadata, still images, video and audio intercommunications among team members, can all be a product of typical ROV operations. In many situations, data generated from ROV operations could benefit from shoreside processing. Real-Time Data Streaming, Bulk Data Transfer, In Situ Processing via Telecommunications Network and Pre-Process Data Shipboard are all valid options.

Real-Time Data Streaming

The nature of ROV operations implies data would likely be available for streaming directly to shore in real-time. This presumes satellite network connectivity and adequate bandwidth are available, and can be reliably sustained during operations. See Section 2.1.1, Real-Time Data Streaming, page 6.

Data Subsampling

ROV operations typically generate continuous data streams based on a combination of pushed and polled data from a variety of sensors, at a range of data rates. Defining requirements for optimizing the frequency at which some of these data are sampled would allow for subsampling to reduce data payload, while still satisfying scientific research requirements.

For those data not suitable for real time subsampling, pre-processing is an option, as described in Section 2.1.4, Pre-Process Data Shipboard, page 8.

Large Datasets

ROV data collection can produce large datasets, ranging from hundreds of gigabytes to terabytes, with video typically accounting for the largest volume. Three applications for handling large datasets are described – see 2.1.2, Bulk Data Transfer, page 7, 2.1.3, In Situ Processing via Telecommunications Network, page 7, and 2.1.4, Pre-Process Data Shipboard, page 8.

All of these applications are potentially relevant to ROV operations. Choosing which application(s) to utilize will depend upon specific requirements associated with a given vehicle and/or mission.

AUV

Engineers program AUV dives during an expedition, beginning with basic surveys, and then fine-tuning subsequent dive plans based on reviewing processed data from previous dives. After vehicle recovery from a given dive, large datasets are transferred / downloaded from an AUV to shipboard data storage systems. These data are then often processed to inform planning for the AUV's subsequent dive(s).

Faster data processing equates to potentially quicker AUV turnaround, enabling improved productivity. Quality of processed data is also crucial for decision makers. One method to expedite data processing while providing higher quality is to employ additional personnel, although space constraints often make it impractical to add shipboard staff. Transferring large datasets to shore and/or in situ data processing by shoreside personnel facilitates augmenting limited shipboard personnel with larger shoreside data processing teams, albeit with some technological challenges.

Real-Time Data Streaming

Interviewees familiar with the Sentry AUV report that it routinely transmits data acoustically from the vehicle to the attending surface vessel. Data is said to be suitable for streaming from the AUV surface support vessel to shore, although these very low bandwidth data streams do not fit the typical definition of 'streaming', and are not particularly useful for data processing. It is mentioned, nonetheless, because of its use in real-time mission direction, potentially augmented by shoreside expertise.

Bulk Data Transfer

Section 2.1.2, page 7, describes this bulk data transfer application, while Section 5.2.1, page 40, presents associated technology considerations. A July, 2012, telepresence-enabled AUV mission utilized a shoreside team to process large datasets transferred in bulk from ship-to-shore. Two separate reports concluded bulk transfer to shore, with subsequent data processing, was productive.

> "An expanded shore-based team provided greater daily man hours, additional multidisciplinary skill sets and greater intellectual capital to the at-sea cruise. This enabled a higher level of data processing and analysis between the ship and shore, and led to more efficient use of AUV bottom time." [4]
>
> "We began this expedition uncertain of whether one could do AUV-based research from shore that would meaningfully entrain the next generation of scientists. The resounding answer, with >6 terabytes of data to explore and >80 person-hours per day to undertake this data exploration, was: ABSOLUTELY." [5]

A third report was also largely positive, although qualified its endorsement.

> "Remote data processing was an effective tool with a few limitations. The most significant limitation on this cruise was effective file transfer. The overall bandwidth was adequate, but it needed to be adapted for the situation." [6]

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[4] Kelley Elliott. EX1205 LEG 1: Blake Ridge Exploration, Lessons Learned (2013)

[5] Van Dover, C. L.; German, C. R.; Yoerger, D. R.; Kaiser, C. L.; Brothers, L. Telepresence field research experience for undergraduate and graduate students: An R/V Okeanos Explorer/AUV Sentry success story, *American Geophysical Union Conference* (December, 2012)

[6] C. L. Kaiser, J. C. Kinsey, W. Pinner, D. R. Yoerger, C. R. German and C. L. Van Dover, "Satellite based remote management and operation of a 6000m AUV," 2012 *Oceans*, Hampton Roads, VA, 2012, p 6. doi: 10.1109/OCEANS.2012.6404900

In Situ Data Processing

An alternative to bulk data transfer described above, is to have shoreside personnel connect via network access to shipboard data systems. This would allow processing data in situ, thus avoiding moving large datasets between ship / shore. See Section 2.1.3, In Situ Processing via Telecommunications Network, page 7.

Data Pre-Processing

A technique to effect more efficient AUV data processing is to pre-process large datasets prior to transferring to shore. Reducing data volume by pre-processing complements bulk data transfers by reducing network bandwidth requirements. See Section 2.1.4, Pre-Process Data Shipboard, page 8.

HOV

Similar to AUV operations, data is downloaded from an HOV after vehicle recovery. Processed data is then used to inform planning for subsequent HOV dives.

While faster turnaround was an important consideration for AUVs, it was not cited by interviewees as consequential in HOV operations. Rather, gaining access to better data processing enables more informed planning.

Real-Time Data Streaming

Real-time streaming is not yet practical at scale, although interviewees indicate technology is currently being tested to increase HOV data streaming capabilities. This technology is similar or identical to that described in Real-Time Data Streaming, above under AUV, page 15.

If / when at-scale real-time data streaming from an HOV becomes practical, then the same principles noted above for AUV real-time data streaming would apply, within whatever constraints are imposed by the technology being deployed for HOV data streaming. Given the physics-based limitations of acoustic data transmission from deep undersea vehicles, substantive changes in HOV data rates are not expected to approach ROV rates in the foreseeable future.

Large Datasets

All of the large dataset processing considerations noted above for AUVs apply to HOV operations. Bulk Data Transfer, In Situ Processing via Telecommunications Network and Pre-Process Data Shipboard are all applicable to processing large datasets during HOV missions.

3.1.2 Mission-Specific Use Cases

Two use-cases for data processing that are not vehicle-specific were referenced by interviewees – ADCP data processing / presentation, and shipboard multibeam data processing. These mission-specific use-cases are described below.

ADCP Data Processing and Presentation

Large datasets are generated during ADCP missions, a small fraction of which are returned to shore via satellite for immediate processing. The full dataset is made available on shore only after a ship returns to port from a mission.

Real-time data streaming is not a feature of current ADCP data processing. Data are heavily subsampled, reducing data volume. Resulting, comparatively small, data files are then transferred to shore via an email attachment.

Daily Email with Attachment(s)

A small collection of log files are aggregated into a compressed archive, e.g. .tar or .zip, and then sent as a daily email attachment. The collection includes a subset of log files from processing and acquisition, some computer system logs and output from diagnostic queries, as well as a snippet of data. Attachment file size is typically 100kBytes ~ 200kBytes.

Averaged Data Subset vs. Raw Data

ADCP data delivered as described above are heavily averaged so, while adequate for viewing as summary data, are not suitable for science. Raw data and/or final processed data products are available only after a ship returns from a mission. Processed data are submitted to R2R for subsequent submission to NCEI (National Centers for Environmental Information) archives.

Shipboard Multibeam Data Processing – Proof of Concept

Interviewees reported success in a recent proof-of-concept mission to process mapping data ashore. Insights from this mission are outlined below.

Shoreside Operations

Explorers-in-training / interns, supervised by a seasoned team, worked 8 hours per day x 7 days per week for the duration of the cruise. Three operational scenarios were identified:

- bulk processing - sending all data to shore for processing, and then returning a subset of processed data to ship
- in situ processing - connecting shoreside personnel to shipboard computing systems to process data without transfer to shore
- operate shipboard sonar equipment from shore - through remote desktop access to shipboard systems.

Satellite networking was reliable and fast enough to support all three operational scenarios described above.

Watchstander Liaisons

Watchstanders were identified as key to the success of this proof-of-concept mission. The primary role is to facilitate communications, and act as liaison between shipboard and shoreside personnel. To cover 24-hour/day operations, interviewees recommended two shipboard watches/day, with watchstanders on a 12-hours on / 12-hours off schedule, implying two shipboard positions.

Situational Awareness

In addition to the situational awareness afforded by watchstanding, interviewees recommended video / voice / data to make participants aware of each other's operational status. This is consistent with requirements stressed by other interviewees – see Section 2.5, Situational Awareness, page 12.

3.2 Remote IT and Instrumentation Support

These use-cases involve shoreside technicians connecting via network access to shipboard systems. See Section 2.2, Remote IT and Instrumentation Support, beginning on page 8, for a description of proposed features and functions.

3.2.1 Vehicle-Specific Use Cases

Use-cases for remote configuration, diagnostics and support of vehicles are largely similar across vehicle types; ROV, AUV and HOV. Descriptions in this subsection, therefore, apply to all three vehicle types.

All vehicle types have a network interface to enable configuring, diagnosing and supporting many vehicle attributes while on deck. These interfaces are typically utilized by shipboard technicians. The use-case being proposed here is to enable shoreside technicians to perform the same functions as shipboard technicians.

Given that vehicle systems are accessed via network interface, shoreside technicians could interact via telecommunications connections in a similar manner as shipboard technicians, performing vehicle set-up, loading configuration files, and the like. Bandwidth requirements are minimal, so the most basic connection would suffice.

A report on telepresence in AUV operations described the vehicle preparation process. "Initial vehicle bootstrapping takes place independent of the network, but as soon as the network hub and main PC104 stack are powered on, all further interaction is via network interface." [7] This implies a possible telecommunications network-enabled division of labor between ship and shoreside personnel.

Interviewees did note there are some cases where physical proximity to a vehicle is useful to be aware of that vehicle's operational status. Providing this level of awareness would add another dimension to this use-case, similar to requirements for Situational Awareness, as described in Section 2.5, page 12. That said, some safety critical functions are not possible to perform remotely, e.g. vehicle tests that require spinning thrusters, turning on and off high power voltages, among others.

3.2.2 Mission-Specific Use Cases

All of the remote configuration / support use-cases identified in this study were associated with vehicles. Interviewees suggested no mission-specific use-cases associated with remote configuration / support.

3.3 Collaborative Troubleshooting

These use-cases describe how shipboard personnel gain access to shoreside personnel with particular engineering / technical expertise.

3.3.1 Vehicle-Specific Use Cases

Use-cases for collaborative troubleshooting are largely similar across vehicle types; ROV, AUV and HOV. Descriptions in this subsection, therefore, apply to all three vehicle types. Vehicles and associated equipment are typically complex systems. This use-case enables access to shoreside experts who can assist shipboard personnel when needed.

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[7] Van Dover, C. L.; German, C. R.; Yoerger, D. R.; Kaiser, C. L.; Brothers, L. An R/V Okeanos Explorer/AUV Sentry success story (December, 2012)

One AUV operations report reviewed for this study sums it up nicely:

> "For the most advanced tasks, AUVs require both broad and deep technical knowledge yet it is often not possible to have individuals with the desired level of experience with all systems at sea." [8]

Another AUV mission report went further in noting potential benefits:

> "We also have discovered the power of telepresence engineering which has significant long term potential. In this model experts on shore can be brought in to help diagnose and solve vehicle problems almost as though they were on the ship. This was used to significant advantage several times." [9]

And a third AUV operations report detailed specific operational considerations:

> "Remote engineering and troubleshooting was found to be exceptionally promising and worthy of further effort. Remote data processing was a valuable addition for a telepresence enabled cruise where a substantial component of the science team was on shore. Remote watch standing and remote launch were both found to be viable though requiring improvement." [10]

A key to successfully implementing collaboration is bidirectional communications between ship and shore, especially voice, video, data and screen sharing. While collaborative troubleshooting is currently practiced, portable communications devices, such as smartphones, if allowed to access the ship's satellite network, could facilitate collaboration with greater ease. Some apps described in Section 2.7, Productivity Application Access, page 13, might provide some added desirable functionality.

Alternatively, dedicated cameras, intercom, phone, desktop/laptop computers and/or other devices could be employed. See Section 2.3, Collaborative Troubleshooting, on page 11, for more details.

3.3.2 Mission-Specific Use Cases

All of the collaborative troubleshooting use-cases identified in this study were associated with vehicles. Interviewees suggested no mission-specific use-cases.

3.4 Custom Software Development

This use-case is similar to both Remote IT and Instrumentation Support, described in subsection 3.2, and Collaborative Troubleshooting, described in subsection 3.3.

A shoreside engineer who is intimately familiar with the software intended to be modified, would first collaborate with the requestor via voice, video, data, screen share and/or other means to gain a complete understanding of the request. When ready to make the modification(s), s/he would establish a network connection to the appropriate shipboard system either to make modifications in situ, or drop new / revised code.

3.4.1 Vehicle-Specific Use Cases

Use-cases for modifying vehicle software are anticipated to be similar across all vehicle types; ROV, AUV and HOV. Shipboard personnel would facilitate a network

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[8] *Ibid*.

[9] Sentry Operations Report for the EX1205 Cruise - NOAA Ship Okeanos Explorer (July 24, 2012)

[10] C. L. Kaiser, J. C. Kinsey, W. Pinner, D. R. Yoerger, C. R. German and C. L. Van Dover, "Satellite based remote management and operation of a 6000m AUV," 2012 Oceans, Hampton Roads, VA, 2012, p 1. doi: 10.1109/OCEANS.2012.6404900

connection to either the target vehicle, or to shipboard systems external to the target vehicle – depending upon where the software resides. This connection enables shoreside personnel to either modify software in situ, or to perform a code drop.

Because of the potential impact to real-time vehicle operations, it is vital to protect systems from being modified during operations. Similar to operations described above in subsection 3.3, Collaborative Troubleshooting, page 18, close collaboration between shoreside and at-sea, therefore, is crucial.

3.4.2 Mission-Specific Use Cases

Certain software applications not tied to real time operations could also benefit from shoreside software development support. An example cited by interviewees is 'tweaking' sensor data post processing routines that may be applicable only to a particular data set. These are distinguished from vehicle software changes by a relatively lower degree of rigor and collaboration necessary in testing and implementing changes. Logistically, version and configuration control are still necessary, but mission and operational risks are lower.

3.5 Situational Awareness

Interviewees with science via telepresence experience emphasized the importance of situational awareness for shipboard as well as shoreside personnel to be better informed about activities in the distant location. See Section 2.5, Situational Awareness, page 12, for a more complete description of this application.

3.5.1 Vehicle-Specific Use Cases

Interviewees indicate that shoreside personnel would benefit from seeing views of the ship's deck, with the intent of enabling them to monitor launch and recovery operations, as well as activities in hangars. This use-case applies to all vehicle types; ROV, AUV, HOV.

In addition to enabling shoreside personnel to view deck and hangar operations, as described above, the following subsections identify use-cases for situational awareness of shipboard activities during vehicle operations.

Shoreside Awareness of Control Van Operations

Views of control van operations along with voice communications between ship and shore were identified as valuable use-cases. One of the awareness requests most valued by interviewees was for navigational data displays.

Shoreside Awareness of Labs

Views of shipboard lab spaces, and voice communications capabilities with personnel in these spaces, was a frequent request among interviewees.

3.5.2 Shoreside / Shipboard Awareness of Common Spaces

Similar to vehicle-specific use-cases, interviewees suggest shipboard personnel would benefit from being aware of activities in shoreside venues, and vice-versa. Shoreside venues of interest mentioned by interviewees include conference rooms, labs and other workspaces when interacting with personnel in those areas.

While many interviewees noted potential value in enabling situational awareness with cameras and voice communication in common areas, those interviewees who are typically shipboard emphasized it should be enabled only when looking to utilize a given space for collaborations with shoreside personnel. The implicit concern is one of the Big Brother Effect, as noted in Section 2.5.2, on page 12.

In the use-cases described above, interviewees identified that key processes to facilitate situational awareness are based on voice communications and video cameras.

Voice – Not Venue Audio

For the purposes of situational awareness of a venue, interviewees consider video to be more relevant than audio – shipboard audio especially is too chaotic to be valuable in most venues. Rather than incorporating generic venue audio, interviewees said that when voice communication is desired, it is best to utilize intercom, phone or other direct connection method.

Video

Cameras would be placed in various shipboard and shoreside venues. Those viewing these cameras could be presented with a variety of options, including the ability to see a multiviewer display of all cameras, a user-configurable view of specific cameras, a single camera view that can be selected by the end-user to view full screen, among other options.

3.5.3 Back-up / Mentoring / Supervising

Additional capabilities enabled by implementing situational awareness were cited by some interviewees. Some suggested skilled personnel located ashore could provide back-up for shipboard personnel. Some also suggested skilled shoreside personnel could supervise and/or mentor shipboard personnel, as described below.

3.6 Community Outreach / Engagement / Career Development

General public outreach, student engagement and career development of future oceanographic technical talent are all identified as candidate applications in Section 2.6, Community Outreach / Engagement / Career Development, on page 12.

Streaming video, with or without audio, from ship-to-shore is one method of outreach and engagement that interviewees note has been successful in engaging general public and student audiences in oceanographic science. While video can grab attention quickly, interviewees with experience utilizing science via telepresence to reach public and student audiences note a key to successful engagement is providing real-time interaction with oceanographers – scientists and engineers.

Drawing upon that experience, the following subsections document use-cases for outreach / engagement with the general public, students and those considering a career as an oceanographic engineer or technician.

3.6.1 Outreach Use Cases

General public and student outreach for engineering and technical operations is essentially the same as that for science outreach and engagement. Availability of shipboard personnel to interact in real-time can be limited due to the nature of operations. Unreliable satellite network connections also present a challenge.

One way these challenges have been addressed in science outreach and engagement is by allowing public and student audiences to interact with shoreside scientists who are in a telepresence environment that is connected to a ship at sea. This allows shoreside science personnel to continue interacting with audiences regardless of ship to/from shore satellite network status.

This same approach could be employed for engineering and technical operations outreach and engagement, substituting scientists with engineers and technicians.

3.6.2 Career Development Use Cases

Limited space shipboard allows for few, if any, opportunities for up-and-coming oceanographic engineers / technicians to gain relevant experience. Performing technical operations functions via telecommunications network connections affords an opportunity to directly engage many more interested people who can be located shoreside. While space shoreside is less an issue than it is shipboard, the same limiting factors – availability of shipboard personnel to interact in real-time, and unreliable satellite network connections – still present a challenge.

Interacting with shoreside engineers / technicians who are filling a mission role via telecommunications network is an option for engaging those pursuing a career. Some interviewees report success establishing a shoreside role using science via telepresence for those pursuing a career, with shipboard and/or other shoreside personnel as mentors. This is also documented in some of the mission reports reviewed for this study.

3.7 Productivity Application Access

Utilizing productivity applications is intended to enable shipboard personnel to access the same apps they would shoreside. A potential challenge is in limiting personal use of applications with a potential for consuming precious bandwidth.

3.7.1 QoS – Traffic Policing and Traffic Shaping

Controlling access to productivity applications is a function of allocating scarce shipboard bandwidth. Managing bandwidth could be on the honor system for some missions. Others may require establishing a formal process of registering personal devices and then using QoS (quality of service) tools to configure IP networks based on a set of usage policies. This is akin to BYOD (bring your own device) policies in many institutional environments.

One Interviewee noted that some ships have implemented multiple Wi-Fi (Wireless Fidelity) access points that are segmented within the shipboard IP network. This configuration is a form of traffic policing according to application type. Wired IP router QoS configuration could also fulfill this goal.

3.8 Watchstanding and Piloting Vehicles

This study does not include shoreside watchstanding or vehicle operation as candidate applications. If/when there is a desire to implement shoreside watchstanding and/or vehicle operation, operational processes and technology requirements would likely be accommodated with modest modifications to systems recommended in this study.

3.8.1 Shoreside Watchstanding

When asked about the feasibility of standing watch from shore, interviewees raised a number of critical considerations that imply it would be impractical to implement at this time. That said, some were eager to incorporate shoreside personnel to assist with watchstanding.

A significant concern was raised about unreliable satellite connectivity. Reliable connectivity is required to enable moving this vital role to shoreside personnel. One interviewee noted that, a failsafe system would be essential to alert shipboard personnel whenever satellite communications were interrupted.

ROV

When considering watchstanding, and especially the navigator's role in ROV operations, interviewees expressed two primary concerns:

- current capabilities are inadequate to enable a shoreside navigator to stand watch
- coordination between a navigator and the ship's bridge is considered a critical aspect of ROV operations, implying a significant effort to ensure continued confidence and operational integrity if moving this role to shore.

AUV

Reports from Sentry cruises, cited previously in this report, document shoreside personnel standing operational watches [11]. These cases, however, also note the presence of shipboard watchstanding personnel simultaneously operating in parallel.

AUV launch and recovery operations are the crucial driver for personnel staffing, and interviewees note that enabling shoreside watchstanding would therefore not reduce shipboard staffing requirements.

HOV

Current certification requirements for a trained person to be standing watch in the top lab make it impractical to implement shoreside watchstanding for HOV operations today.

Establishing processes to enable shoreside personnel to stand watch while ensuring operational integrity, and evolving a new standard for certifying shoreside personnel to stand watch, would be required before shoreside watchstanding could be enabled for HOV operations.

3.8.2 Piloting Vehicles from Shore

No interviewees suggested it is currently practical to directly connect shoreside personnel with shipboard systems to operate vehicles at sea, this despite references to operating vehicles from shore as far back as the 1980's. Some, however, were cautiously optimistic about how shoreside vehicle operation might become practical in future.

That optimism is supported in part by reference to remote piloting of ROVs via satellite, as currently provided by Oceaneering, a supplier of services and products primarily to the offshore oil and gas industry. Optimism about ROVs not withstanding, of the three vehicle types included in this evaluation, AUVs were considered by interviewees as most likely to be the first vehicle type to be widely adapted for routine direct operation from shore. Ocean gliders, a limited form of AUVs, are reportedly already operated in this manner.

[11] Sentry Operations Report for the EX1205 Cruise - NOAA Ship Okeanos Explorer (July 24, 2012)
Kelley Elliott. EX1205 LEG 1: Blake Ridge Exploration, Lessons Learned (2013)

4 Personnel Considerations

Applications described in Section 2, as well as Use-Cases in Section 3, establish criteria for personnel considerations to facilitate them. Skills, staffing levels, scheduling and compensation schemes are all potentially affected by migrating some shipboard technical operations to shoreside personnel.

4.1 Shipboard Personnel

This report focuses on evaluating the viability of implementing technical operations via telecommunications network connections. The only shipboard personnel included in this evaluation, therefore, are marine technicians, and other personnel identified as materially impacting technical operations.

4.1.1 Shipboard Staffing and Scheduling

Shipboard staffing takes into consideration more than just technical operations responsibilities of marine technicians. Vehicle launch and recovery operations often involve 'all hands', including marine technicians. Also, watchstanding was identified as a key consideration in ensuring successful science via telepresence.

Vehicle Launch and Recovery

Interviewees noted that technical personnel typically assist with vehicle launch and recovery operations. Plans to reduce shipboard technician headcount by performing some technical functions shoreside, therefore, would have repercussions on launch and recovery operations.

A Jason mission was scheduled for shortly after initial interviews for this study were completed. One goal of this mission was to evaluate single-body operations, which interviewees had noted would likely reduce the number of personnel required for vehicle launch and recovery. Follow-up interviews indicate success, thereby lessening concerns about reducing shipboard marine technician headcount.

4.1.2 Shipboard Personnel – Direct and Indirect Costs

Research to determine direct and indirect shipboard personnel costs included a review of WHOI's personnel compensation records, consultations with NSF, interviews with representatives of oceanographic research institutions and a compensation survey of oceanographic research vehicle operators.

Direct Costs

Personnel compensation for shipboard activities, whether paid to staff or contractors, can be expressed as a day rate, which varies according to function / skills and administrative overhead allocations that can differ across institutions. Analyses described in Section 6, Analysis and Recommendations, page 50, reference an average (arithmetic mean) of personnel compensation values gleaned from a survey.

Another consideration is whether to staff a marine technician role with a full-time employee, or a contractor. See subsection 4.4, Rationale for Utilizing Staff versus Contractors, page 29, for more details on this topic.

Indirect Costs

In addition to direct costs for personnel compensation, there are less objectively quantifiable costs, such as those associated with the value of a berth aboard ship. See subsection 6.2.2, Berth Scarcity / Surplus, on page 62, for more details.

4.2 *Shoreside Personnel*

Differing expectations about shipboard and shoreside personnel scheduling and compensation were identified by many interviewees as significant considerations when implementing science via telepresence operations.

4.2.1 Shoreside Staffing and Scheduling

Experiences from science via telepresence operations reveal challenges in reconciling shipboard with shoreside personnel scheduling. Some interviewees suggest additional shoreside staffing is one possible solution.

Scheduling Logistics

Workday

Two common shipboard workday scheduling patterns were identified during discovery for this evaluation: 4 hours on / 8 hours off, and 12 hours on / 12 hours off. These work schedules do not match-up well with typical shoreside 8-hour or 10-hour workdays.

Shipboard personnel are also sometimes called back to work during their 'off hours' if operational situations require it. Given shipboard personnel are captive aboard ship, it is easy logistically to fulfill these needs. Shoreside personnel working traditional workdays, however, are likely less available.

While it is anticipated that shoreside personnel may work remotely from home, this may not be true in all cases. If not working remotely, then traveling to and from a place of work, as well as non-work related commitments during 'off hours', present different logistics that complicate shoreside personnel availability.

Shipboard Consecutive Workdays / Shoreside Workweek

Another consideration is consecutive workdays, which is continuous for the duration of a mission when shipboard. Shoreside work schedules are normally based around a five-day workweek.

Concurrent Shipboard / Shoreside Scheduling

While one could assign shoreside personnel to work on the same schedules as shipboard personnel, resulting multiple personnel and/or overtime costs would be significant. The cost / benefit model allows testing multiple 'what if' scenarios, including different staffing and compensation schemes. Some of these compensation scheme options are evaluated in multiple cost / benefit scenarios in Section 6.2.5, Scenario, beginning on page 65.

Additional Staffing Requirements

Depending upon the level of activity anticipated for shoreside technical operations support, multiple shoreside personnel might be required, implying requiring additional shoreside personnel – above shipboard staffing levels – to provide equivalent coverage to what is available shipboard.

Those with shoreside science via telepresence operations experience suggest that even for relatively modest operations, having multiple shoreside technical operations personnel available for a given mission is also prudent to prevent burnout.

Current WHOI staffing policy does not support overtime compensation, and requires prior authorization for non-uniform work hours for many staff personnel. This implies either needing to:

- Add Staff Personnel – adequate to support shoreside technical operations
- Modify Overtime Compensation Policy – to facilitate staffing shoreside technical operations with WHOI employees
- Utilize Contractors – see 4.2.3, Shoreside Compensation, also see 4.4, Rationale for Utilizing Staff versus Contractors, page 29

4.2.2 Shoreside Tech Resource Pool

One staffing concept is to provide a shoreside technical operations resource pool of geographically distributed technicians with varying skills who would be available 'on-call'. Some interviewees thought the idea had merit, but most questioned the feasibility of implementing a budgeting model for such an arrangement.

Given that the current norm for compensation is based on a day-rate model, implementing a per-incident fee across a technical resource pool would represent a significantly different compensation scheme. Administrating financial transactions for this pooled technical resources arrangement would require infrastructure and resources that currently are not in place.

4.2.3 Shoreside Compensation

Two compensation models were identified for shoreside technical operations support via telecommunications network: per-incident, and per-mission. Also of note is a hybrid of these two compensation models.

Analyses described in Section 6, Analysis and Recommendations, beginning on page 50, reference an average (arithmetic mean) of personnel compensation values gleaned from a survey of oceanographic research vehicle operators. Those values are:

Personnel Compensation	At Sea		Ashore	
	Staff	Contractor	Staff	Contractor
Data Processor	$ 689	$ 809	$ 627	$ 588
ROV Engineer	$ 712	$ 741	$ 693	$ 788

Table 2 Personnel Compensation – averages from survey

Per Incident

One approach to shoreside compensation is structured with a base day-rate to be on-call for the duration of a mission, plus a per incident hourly rate when responding to a request for services. A typical structure for per-incident compensation would also set a cap on the maximum compensation for a given day. For example, one might establish a per-incident compensation scheme with the following:

base-rate = $200 / day

per-incident hourly rate = $125 / hour

capped at a daily maximum = 6 hours or $950 / day

Advantages of this type of compensation arrangement are that it minimizes costs for situations where minimal activity is anticipated, while ensuring a person is available 'on call' for the duration of the mission. If anticipating more activity, however, then this minimal approach may not suffice, either requiring raising the daily hourly cap, hiring multiple personnel fill the role, or a combination of the two.

Per Mission

An alternative, geared to higher levels of activity, is a per-mission compensation scheme. In this approach, the base day-rate is higher, as it is based on a full workday, and the hourly 'overtime' rate is lower than the per-incident hourly rate.

A cap on total hours in a single workday can also be set for this per-mission compensation scheme. For example, one might establish a per-mission compensation scheme with the following:

day-rate = $750 / 8-hour day
overtime hourly rate = $100 / hour
capped at a daily maximum = 12 hours or $1150 / day

Advantages of this per-mission compensation model are immediate availability during a technician's scheduled workday, and better economy for missions anticipating more than a few hours per day of activity for shoreside technicians.

Hybrid

When reviewing options, a hybrid of per-incident and per-mission compensation schemes seemed an appealing proposition. The thinking is that one person who is compensated on a per-mission basis can be a stable resource who is cognizant of mission status at all times, and can address most service requests directly. Taking this a step further, this per-mission technician could potentially monitor multiple missions simultaneously.

When service requests are outside of this per-mission technician's area of expertise, or hours would exceed the daily cap, then s/he can call upon someone who is available on a per-incident arrangement.

4.3 Balancing Shipboard / Shoreside Skills

One of the advantages noted for enabling technical operations via telecommunications is increased shipboard access to shoreside personnel with specialized skills. There are several examples of this noted in Sections 2 and 3. For example, see Section 2.2.1, Instrumentation Support, page 8, Section 2.3, Collaborative Troubleshooting, page 11, Section 2.4, Custom Software Development, page 11, among others.

Typically, personnel with specialized skills are scheduled to go to sea for a given mission that would benefit from that particular expertise. Enabling technical operations via telecommunication network connections would allow the expertise of a given skilled individual to be available to multiple ships. This newly enabled capability, though, presents new questions about how to allocate skilled resources.

4.3.1 Specialists Shipboard

Mission objectives may ideally be served with highly skilled technical operations personnel shipboard. A decision to deploy such a person shipboard would normally imply dedicating this resource exclusively to that specific mission, to the exclusion of supporting other concurrent missions.

If enabled, then technical operations via telecommunications would allow that skilled person to provide some level of cross-vessel support. This scenario is reported to work with varying degrees of success, although shipboard work schedules are reported to severely limit an individual technician's availability for assisting other missions, so is typically employed only in unusual or extreme situations.

Based on current operational norms – even when considering experiences with science via telepresence-enabled missions – it would appear that shipboard assignments for specialists result in that resource being mostly, if not entirely, dedicated to the specific mission to which they are assigned. Operational practices may evolve in future to accommodate shipboard personnel providing cross-vessel support as a norm, although such a model is not currently foreseeable.

4.3.2 Specialists Ashore

A significant benefit of enabling technical operations via telecommunications identified by interviewees is greater access to specialized expertise. Several examples that highlight benefits of accessing shoreside expertise while at sea are described in Sections 2 and 3. See Section 2.2.1, Instrumentation Support, page 8, Section 2.3, Collaborative Troubleshooting, page 11, Section 2.4, Custom Software Development, page 11, Section 3.3.1, Vehicle-Specific Use Cases, page 18, among others.

4.3.3 Skilled Satellite Network Technicians

A point reiterated many times by those with experience using science via telepresence is the need for skilled satellite network technical personnel aboard ship. This point was highlighted by technical personnel and scientists alike, with some senior scientists emphasizing the point by stating they would willingly trade-off berth space allocated to science, to ensure appropriately skilled telepresence technical personnel are aboard ship.

The rationale for this emphasis on telepresence technical personnel is based on experience that teaches satellite communications network set-up is anything but straightforward. Some interviewees suggested this was likely due at least in part to non-standard configurations aboard ship.

Crucial Role During Set-up

When considering the value of a skilled satellite technician, a particular emphasis is placed on initial set-up during mobilization and during the first part of a cruise – often during transit. Establishing an initial satellite connection often involves the most effort for a cruise. That is not to say there are never issues during a cruise, but comparatively, satellite technicians are typically busiest at the beginning of a cruise.

Impact of Portable 'MTU' versus Integrated Shipboard System

Many interviewees have had experience with science via telepresence using video streaming from ship-to-shore. These set-ups often require utilizing an MTU (mobile telepresence unit) that is brought aboard ship for a given mission, temporarily connected to ship satellite communications systems, and then disconnected at the conclusion of the mission.

Temporarily setting-up and dismantling a telepresence system aboard different ships with varying infrastructure presents logistical challenges that are currently addressed with highly skilled personnel. This is consistent with observations noted above, and might explain why scientists and others with experience with these systems strongly recommend including shipboard telepresence technical specialists.

Technical operations via telecommunications networking is a less demanding application than video via telepresence, as video streaming typically requires setting up intercom matrices, video codecs (encoders / decoders), along with other systems.

Technology system concepts presented in Section 5, Technology Options, beginning on page 32, include many options that function within existing shipboard satellite communications infrastructure, and would not require extra features enabled by an MTU.

Simpler requirements of technical support via telecommunications, as compared to video streaming with intercoms and other real-time synchronous demands, imply a comparatively less complicated operational dynamic. Existing shipboard satellite communications operations skills, therefore, are considered adequate to support technical operations via telecommunications.

4.4 Rationale for Utilizing Staff versus Contractors

The choice to utilize an employee versus a contractor is based on multiple factors – some economic, and some logistic. Compensation is a significant economic consideration, as are institutional overhead chargeback policies, which differ between staff and contractors. Availability of appropriately skilled personnel to meet requirements for a given objective is an additional logistic factor.

Typically, contractors receive a premium 'day rate', whereas staff personnel receive a salary or hourly rate. On its surface, this makes contractors appear more expensive than staff. The economics, however, are more nuanced than they may first appear.

Institutions typically chargeback overhead costs based on a percentage of personnel compensation. The percentage an institution charges back for overhead often differs between staff and contractors. These differing policies, therefore, also factor into economics associated with choosing to utilize a staff person or a contractor.

Direct personnel compensation costs are another significant economic factor, with staff typically paid less per hour or per day than contractors. Premium contractor compensation notwithstanding, flexibility to employ contractor personnel with specific skills only when needed, can facilitate more efficient personnel utilization. There are two primary factors to consider with personnel utilization flexibility:

- keeping staff gainfully employed
- efficiently fulfilling unique requirements of a given objective

Operations evaluated for this study appear to be largely project-based, which by their nature, present varying, irregular and often unpredictable demands on personnel resources. Three options are identified for staffing to fulfill these varying demands – full-time permanent staffing, on-demand staffing, and a hybrid of the two.

4.4.1 Full-Time Staff

One option for staffing is to anticipate the most demanding requirements, and hire full-time permanent staff with appropriate skills to meet those demands. Unless project requirements are relatively unchanging, however, this approach is likely to result in idle personnel when overall project demands are at less than their peak.

4.4.2 On-Demand Contractors

Hiring appropriately skilled contractors to fulfill project requirements only when needed is one staffing approach for meeting varying demands. More efficient scheduling that is characteristic of on-demand staffing can minimize idle time for personnel, though it typically involves higher personnel compensation rates compared to that for full-time staffing.

4.4.3 Hybrid Full-Time Staff / On-Demand Contractors

Given the project-based nature of WHOI operations, economics do not appear to justify employing all full-time staff. Neither does it appear advantageous to employ all on-demand contractors. Rather, staffing economics and logistics can seemingly be optimized through a hybrid combination of the two approaches.

Base-Level Staffing

Determining a quiescent sustained activity level would establish a base staffing requirement that would minimize idle personnel time. While this base staffing approach would result in high personnel utilization, it would by definition fall short on fulfilling requirements during peak demands.

Additionally, it is challenging to hire a core staff with all the skills needed for varying projects. So, whatever base staff is hired will likely need augmenting at times to fulfill unique skills requirements associated with specific projects.

Contractor Augmenting

Meeting project requirements during peak activity times is most efficiently met – both economically and logistically – by augmenting full-time staff with contractors. The same is true when needing to fulfill project demands for unique skills, if qualified staff are unavailable to accommodate specific requirements.

While contractor compensation rates are higher per day than full-time staff, hiring on-demand maximizes their utility, so can be more cost effective overall.

4.4.4 Jason Operations – An Example

A full evaluation of this personnel compensation topic is beyond the scope of this study. Not wanting to do an injustice to this important topic, therefore, no attempt is made to exhaustively evaluate all aspects of full-time staff versus contractor utilization. Rather, an example based on WHOI's Jason operations is presented to help provide context for how the cost / benefit model may be utilized to evaluate the economics of various staffing options.

Jason Operations Logistics Overview

The Jason ROV system, while based at WHOI, spends a substantial amount of time away from Woods Hole. Because Jason is a flyaway system that operates on a variety of platforms, it – and its associated team – are aboard research vessels for only a portion of this time. For the remainder of its time away from home, which is substantial, Jason is either in transit by container ship and truck, or in temporary storage.

Non-Operational Downtime

During Jason's downtime, the operations crew does not have access to the vehicle or the control vans. It can be difficult to find funded work for some members of the operational team during the transit and non-operational periods, so WHOI employs a team of highly skilled contractors to augment the permanent team members.

Personnel Compensation

Typically, contractors receive a premium day-rate, potentially making them more expensive than permanent employees during their time at sea. This premium day-rate associated with hiring contractors is somewhat balanced out by paying for their services only when Jason is productively deployed at sea.

WHOI employs a significant number of contractors to support Jason operations. This choice implies economics favor hiring contractors when compared to idling full-time staff while the Jason system is in transit and during non-operational downtime.

Institutional Overhead Chargebacks

WHOI recently modified its overhead chargeback policies, establishing an overhead charge based on a significantly higher percentage of contractor compensation, as compared to the percentage of staff compensation. This policy affects the calculus associated with staff / contractor hiring, making contractors less economically attractive when compared to full-time staff.

The cost / benefit model includes a set of variables that allow including any combination of full-time staff and/or contractors in a given scenario – see Personnel Costs – Compensation per Mission, beginning on page 54, for details about this aspect of the cost / benefit model. Also, two scenarios evaluated for this study specifically quantify cost implications of utilizing full-time employees versus contractors – see Scenario 1 – ROV Data Processor; Employee, page 66, and Scenario 2 – ROV Data Processor; Contractor, page 68.

5 Technology Options

Based on evaluations of Applications from Section 2, Use-Cases from Section 3 and Personnel Considerations from Section 4, this section considers technology implications of implementing technical operations via telecommunications network. Technology options described in this section are conceptual. The intent is to identify a framework to support applications, use-cases and personnel requirements described in this study, as well as to accommodate future requirements, wherever possible.

Subsection 5.1 addresses overall shipboard, shoreside and satellite communications infrastructure requirements to enable technical operations via telecommunications network. Subsection 5.2 focuses on application technology platforms installed on that infrastructure, and intended to support specific candidate applications.

5.1 Network Infrastructure

This study relied upon interviewees' perspectives about the current status of shipboard and shoreside network infrastructure – no independent evaluation was conducted to validate these perspectives. For the purposes of this study, this approach is considered adequate for cost / benefit analyses focused on human resources. That said, Recommendations in Section 6.3, page 82, advise assessing each individual ship's as well as each shoreside venue's infrastructure, prior to implementing any technology upgrades intended to enhance telecommunications capabilities.

The following subsections describe technology requirements for each of three broad categories – satellite network connectivity, shipboard network and shoreside network.

5.1.1 <u>Satellite Network Connectivity – Ship to/from Shore</u>

Shipboard and shoreside networks are connected via satellite. Transmit and receive platforms, located in both locations, facilitate a bi-directional network link.

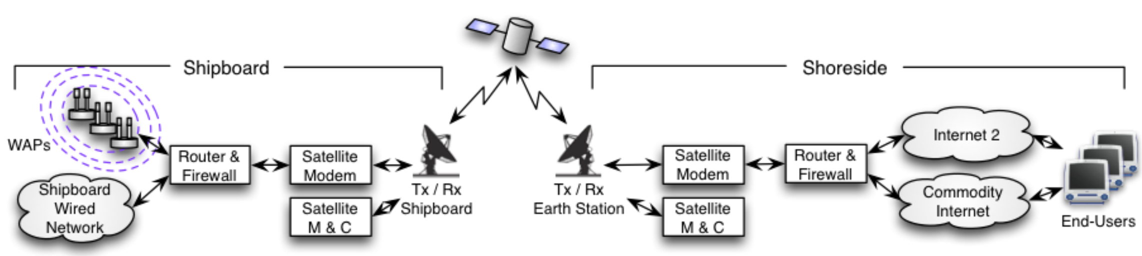


Figure 1 Ship to/from Shore Satellite Network Connectivity Conceptual Diagram

One categorization of satellites is by the radio frequency spectrum they operate in. C-band, Ku-band and Ka-band are all used in satellite communications, with each having unique characteristics. In oceanographic applications, C-band is commonly utilized for open ocean cruises, while Ku-band is most often used for missions operating on continental shelves. Ka-band is not typically utilized at sea, partially because it is particularly susceptible to disruptions from weather.

Satellite communications bandwidth is contracted for with third-parties. Multiple third-party service options were identified during discovery, including Fleet Broadband – a service from Inmarsat, and HiSeasNet – an NSF-funded service operated by UCSD / Scripps Institution of Oceanography. This assessment references services provided by HiSeasNet as the baseline for evaluation. HSN can currently support 40 ~ 50 Mbits/sec via C-band on Ocean Class vessels.

Current satellite communications infrastructure designed to support science via telepresence will support deploying technical operations via telecommunications with no additional capital investment. Bandwidth requirements for technical operations via telecommunications are also significantly less than for science via telepresence.

Some modest shipboard / shoreside networking infrastructure modifications, and/or deploying network administration applications would offer enhanced features and capabilities. Provisioning shipboard subnets might also be desirable. See subsection 5.1.2, Shipboard Network, page 36.

Satellite Antenna, Stabilized Tracking, Amplifiers and Modem

Research vessels, including UNOLS ships that are the focus of this evaluation, are all currently equipped with satellite communications systems. The relatively low-bandwidth requirements of most candidate applications and use-cases identified in Section 2 and Section 3, imply no additional investment in shipboard satellite transmission / reception systems is required in most cases.

Should operational requirements dictate higher bandwidth requirements than current shipboard satellite communications systems are capable of supporting, then capital upgrades to those systems would be in order. One candidate application that may exceed current bandwidth capabilities of some ships is Bulk Data Transfer, described in Section 2.1.2, page 7.

Due to wide variations among systems installed on ships, an evaluation of each ship's specific satellite communications infrastructure is recommended to ascertain bandwidth capabilities. Assessing satellite communications capabilities of individual ships is beyond the scope of this report. That said, the cost / benefit financial model, in its current form, can be utilized to evaluate financial implications of shipboard satellite communications upgrade scenarios.

Satellite Modem Standardization

Equipping all ships with similar satellite modems would ensure a common monitoring and control interface, and enable operational efficiencies, as described in Section 2.2.2, Satellite Communications Systems, page 10.

While operational efficiencies could potentially be realized, cost savings would be unlikely to justify wholesale replacement of existing satellite modems. Recommendations in Section 6.3, page 82, advise standardizing modems going forward, as part of normal shipboard satellite system upgrade cycles.

Maximizing Satellite Bandwidth Efficiency

Several approaches for maximizing satellite spectrum utilization have been identified as potentially viable. Modulation, FEC (forward error correction), CRMA (Code Reuse Multiple Access), PCMA (Paired Carrier Multiple Access), File Acceleration and PEP (Performance Enhancing Proxy) are all described in the following subsections.

Two of the identified approaches fall under a category of 'carrier in carrier': CRMA and PCMA. These techniques are based on multiplexing multiple transmissions into a single carrier signal originally intended to support a single transmission. File transfer, file acceleration and PEP, are techniques for maximizing bandwidth utilization at the TCP/IP layer.

In addition to increasing bandwidth efficiency, one might consider reducing data payloads to make more efficient use of whatever bandwidth is available. Data subsampling is one approach. Another is to deploy data management software applications that are designed to reduce data volume.

Modulation

Satellite communications involve modulating a continuous carrier signal with information / data intended to be transmitted via that carrier. The carrier signal is a continuous sequence of sine wave pulses, each of which is referred to as a symbol. Modulation is typically based on some version of phase shift keying, which shifts a carrier by ‘x’ degrees from the carrier sine wave zero crossing.

QPSK (quadrature phase shift keying) shifts a signal by 90 degrees, or ¼ of a full sine wave. 8PSK shifts a signal by 45 degrees, or ⅛ of a full sine wave. Smaller sine wave fractions imply more data sent through a given spectrum.

While higher-order phase modulation techniques are able to send more data through a given spectrum, it comes at a tradeoff of satellite power and data transmission reliability / integrity. Bandwidth cost calculations in the accompanying financial cost / benefit model are based on QPSK, which is consistent with conservative practice.

Forward Error Correction

FEC is a coding technique employed to improve communications reliability over intermittent or noisy networks. Provisioned at the source transmission, FEC involves sending redundant data bits in anticipation that some will be lost between source and destination.

A range of FEC configuration settings allows for sending more or less redundant data, depending upon the perceived reliability of a network connection. Sending more redundant data improves reliability only up to the point of overcoming whatever deficiencies are present in the network – additional FEC results in less efficient bandwidth utilization, so FEC settings are optimized according network conditions. Ship to/from shore satellite connections are often unreliable and noisy, so FEC is considered a necessity.

Code Reuse Multiple Access

CRMA allows sending multiple simultaneous transmission ‘bursts’ on a single frequency, by staggering ‘bursts’ to start at different times. This technology has not yet been tested by HiSeasNet, so is not included in this evaluation. If future testing indicates CRMA is of value, then there would be a capital cost for upgrading shipboard and shoreside satellite modems.

Paired Carrier Multiple Access

PCMA superimposes transmit and receive carriers, rather than using separate spectrum for each, theoretically doubling spectrum utilization. Although that potential is rarely fully realized, potential savings are nevertheless considerable.

HSN has been testing PCMA with encouraging results – see ‘UCSD / HiSeasNet – Bandwidth Testing Results’ in the Appendix. Results from this PCMA testing partially inform a recommendation for the satellite bandwidth efficiency range of values described in Satellite Spectral Efficiency, on page 57.

Performance Enhancing Proxy

PEP technology has not yet been tested, so is not included in budget planning. Testing is necessary, as inquiries to vendors of PEP systems reveal they have not done compatibility testing with other efficiency technologies that are based on manipulating TCP/IP packets, such as file acceleration.

If future testing indicates PEP is of value, then there would be a capital cost for upgrading the shipboard data router / switch, or for purchasing a dedicated satellite communications appliance, e.g. Advantech PEP 9160, from Advantech Wireless.

File Transfer Options

Four possible methods were identified for transferring large files:

- FTP (File Transfer Protocol) – uses TCP
- UDT (UDP-based Data Transfer Protocol) – uses UDP
- GridFTP (Open Grid Forum derivative of FTP) – based on FTP
- BBCP – similar to GridFTP – developed at Stanford University
- File Acceleration via:
  - Aspera FASP
  - FileCatalyst

File Transfer Protocol and Data Transfer Protocol

FTP is probably the most familiar protocol for sending data files via IP networks. UDT is designed specifically for transferring large data files, and is shown to perform well when transfers are via high-speed networks.

GridFTP and BBCP

The Open Grid Forum created a derivative of FTP called GridFTP. BBCP was created by the Stanford Linear Accelerator Center. Of particular interest for satellite communications is network fault tolerance, including intermittent connections. Also of interest is the ability to handle large files. BBCP has been used to transfer multibeam sonar files from ship to shore on several occasions.

File Acceleration

Based on a client server architecture, file acceleration is achieved through proprietary software from multiple vendors. A recent verification cruise on the R/V Sally Ride attempted to test one file acceleration offering from Aspera, although tests were inconclusive.

If future tests prove there is value in implementing file acceleration, then there would be no additional costs for shipboard implementation, beyond existing shipboard infrastructure – file acceleration client is free software installed on existing shipboard and portable computer platform(s). The free shipboard file acceleration client connects to a shoreside server, which is described below in subsection 5.1.3.

Three vendors who supply file acceleration software and/or services are:

- Aspera
- FileCatalyst
- Signiant

Develop Apps to Use Lower Bandwidth

File Transfer Options described above in the previous subsection address techniques for maximizing data throughput to fully exploit available satellite communications network capacity. Another approach to gaining efficiencies is to minimize data volume, thereby reducing bandwidth requirements.

These approaches can both be implemented together, so that reduced payloads can harness the full capacity of optimized network data transfers.

Data Subsampling / Consolidation

Many shipboard data sources are being polled at a 1Hz rate. While this may serve shipboard data visualization requirements, it may not be necessary for the purposes of gathering valid datasets.

Interviewees indicate many data sources can be subsampled to reduce data stream / data volume, while still retaining the integrity of associated datasets.

iRODS

An open source data management software suite, iRODS (Integrated Rule-Oriented Data System), offers one approach to reducing data volume. The suite includes a much more comprehensive set of data management tools to address large scale storage and access, which also might be of interest.

5.1.2 Shipboard Network

Figure 2 below shows a conceptual overview of shipboard data network, including satellite connection, router, firewall and WAPs (wireless access points).

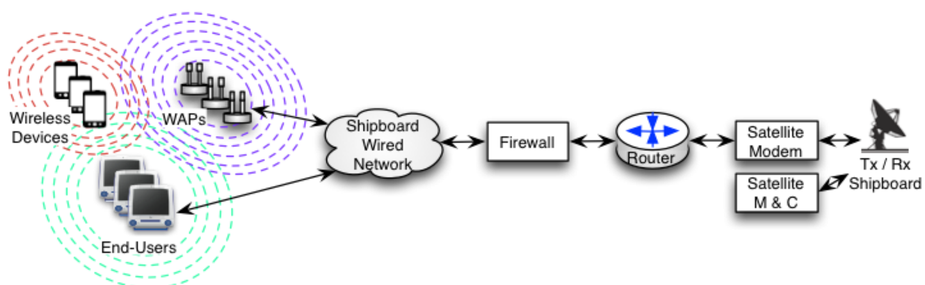


Figure 2 Shipboard Data Network Conceptual Diagram

Wired Ethernet

Fixed shipboard locations are connected via wired Ethernet cables to a data network router. Different ships have different configurations, so an audit of specific ships' networking infrastructure is recommended prior to implementing any modifications.

Wireless Access Points

Many shipboard networks already include some WAPs in their IP network infrastructure. Similar to Satellite Antenna, Stabilized Tracking, Amplifiers and Modem described above, assessing each individual ship's requirements is advised, which is beyond the scope of this effort.

If shipboard evaluations determine additional WAPs are required, these should be specified to be compatible with either existing IP network infrastructure, or as part of a shipboard network upgrade. The current cost / benefit model in the accompanying Excel® workbook accommodates evaluating financial impacts of either approach for implementing WAP technology.

Subnets

A thorough assessment of shipboard / shoreside network requirements is beyond the scope of this effort. Evaluation is recommended, therefore, to determine how to optimize network subnet configurations to best align with NDSF requirements. Anecdotal evidence reveals multiple shoreside subnets are currently supporting NDSF operations – Alvin, Jason and Sentry.

Allocating bandwidth among shipboard user groups might be addressed through shipboard subnet configuration. Three user groups – ship operations, science and NDSF technical operations – have been identified. Establishing minimum bandwidth allocations for each user group would enable a group to access more than the minimum when available ship to/from shore bandwidth exceeds total user demands, while also guaranteeing minimum bandwidth when total user demands exceed ship to/from shore satellite network capacity.

5.1.3 Shoreside Network

In Figure 3, below, the shoreside network is shown in two halves. On the left is a conceptual representation of a satellite service provider's network topology, and on the right is a representation of WHOI's network topology.

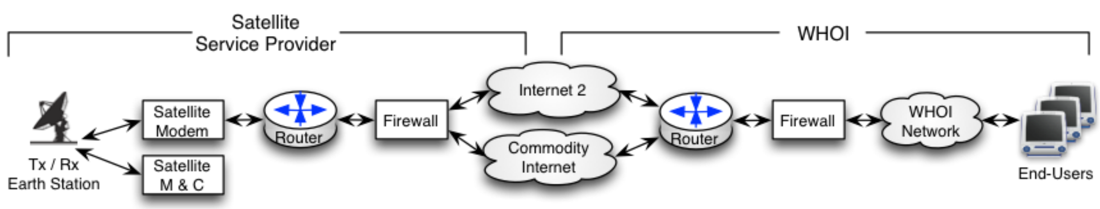


Figure 3 Shoreside Data Network Conceptual Diagram

Satellite Service Provider

Provisioning ship to/from shore bandwidth is handled by a satellite service provider, as described above in subsection 5.1.1, beginning on page 32.

Satellite Earth Station

The left side of the conceptual network diagram shown above includes a satellite earth station, which is the shoreside gateway for ship to/from shore network communications.

HSN, the reference satellite service for these evaluations, operates an earth station that is co-located with their data center.

Terrestrial Network Connection

In addition to acting as a gateway for ship to/from shore network connectivity, a satellite service provider connects to/from a client's network. In WHOI's case – and as is anticipated for all institutions associated with UNOLS – this connection is via terrestrial data networks.

Most commonly for educational and research institutions, the terrestrial network of choice is Internet2. Commodity Internet is also an option. HSN, the satellite service provider referenced in this evaluation, operates a datacenter with 200 Gbit/sec peering capacity with these terrestrial networks.

WHOI

Looking at the diagram in Figure 3 above, the right side shows WHOI's conceptual network topology. Existing campus networks interface with the satellite service provider's ship to/from shore gateway, via terrestrial network – either Internet2 or commodity Internet, or both. This conceptual network topology is anticipated to be typical of all UNOLS-associated institutions.

Anecdotal evidence suggests IP multicast is currently supported within WHOI's campus network. IP multicast is desirable to support those applications requiring simultaneous distribution to multiple locations.

File Acceleration

Subsection 5.1.1, under the heading File Acceleration on page 35, notes that file acceleration operates as a client / server application, with a free client application shipboard, and a server shoreside. The shoreside server may be located anywhere in the shoreside network – at WHOI, at another UNOLS institution or at a satellite service provider. Some file acceleration software vendors also offer a SaaS (software as a service) hosted service.

As described previously, file acceleration has not yet been tested satisfactorily, so is not included in budget planning. If future tests demonstrate there is value in file acceleration, then there are two cost models to consider for Shoreside implementation:

- server license purchase and annual support
  - initial purchase plus annual software maintenance
  - one license if implementing at a single site that serves all ships and shoreside institutions
  - would need multiple licenses if implementing multiple shoreside sites
  - license based on bandwidth expressed in Mbits/sec
- SaaS – pricing based on volume of data

File acceleration server software installation does not require systems integration; it can be handled by IT staff with assistance from whichever file acceleration software company is selected. File acceleration vendors include:

- Aspera
- FileCatalyst
- Signiant

5.1.4 IT Administration

An evaluation of current shipboard / shoreside IT administration practices is beyond the scope of this effort. Anecdotal information suggests shipboard IT administration currently is performed at sea, with little – if any – coordination with shoreside IT network personnel.

Enabling shoreside technical operations implies performing more IT administration from shore, rather than shipboard. Additional IT administration tools will help facilitate this remote IT administration management requirement.

The conceptual network topology shown in Figure 3 on page 37, resembles a private cloud computing model. Tools developed for a cloud environment, therefore, can be deployed by IT administrators and/or those assigned to provide technical operations via telecommunications, enabling them to remotely support provisioning, monitoring and reporting of shipboard and shoreside IT systems.

In fact, one option might be to contract with a cloud computing service provider for IaaS (infrastructure as a service), PaaS, (platform as a service), or other similar cloud service offerings. This cloud service option is not explored in this evaluation, as it is beyond the scope of the project.

In addition to common IT administration functions, such as setting up user accounts / identity management, orchestrating workflow automation, status monitoring, among others, tools are available to manage more advanced features, e.g. SDN (software defined networking).

Remote administration could be accomplished by using remote desktop, remote login via SSH, or other similar utilities. While functional, WHOI might consider some commonly used IT administration applications that offer a much more robust set of tools. Some of these commonly used IT administration tools are listed below – this is intended to be a representative list, not an exhaustive one.

Some applications are open source, others are enterprise applications requiring paid licensing. Many vendors offer applications suites to address multiple facets of remote IT administration. Listed vendors include hyperlinks to their websites.

Overall IT Management

These vendors offer a core application with modules for configuring and managing overall IT infrastructure.

- Ansible Tower
- Apache CloudStack
- Hewlett-Packard Enterprise Helion Eucalyptus
- Oracle OpenStack
- Puppet Cloud Management
- VMware NSX

Hypervisor

Monitoring and managing virtual machines in a cloud computing environment is supported by the following applications. These applications enable robust status monitoring – network, compute and storage. Most allow customizing dashboards to provide status views tailored to individual requirements.

- Citrix XenServer
- Microsoft Hyper-V
- Oracle VirtualBox
- Plexxi Private Cloud
- VMware vSphere

Software Defined Networking

Configuring shipboard / shoreside networks, compute and storage environments can be facilitated through SDN tools. While it is feasible to develop custom tools using

SDK (software development kits) and/or APIs (application program interfaces), it is advisable to consider applications listed below.

All of the vendors listed under Overall IT , above include capabilities to manage SDN configurations. Those listed here offer modules and/or application suites specifically designed for SDN administration.

- Chef
- Cisco features two offerings:
  - Prime Data Center Network Manager (DCNM) for FabricPath
  - Application Centric Infrastructure (ACI)
- Puppet Configuration Management
- Salt Open Source, and Salt Enterprise
- VMware NSX

Identity / Access Management

Managing end-user accounts, including authentication, credentials, configuring access privileges, among other functions, can be accomplished in a variety of ways. A familiar and widely deployed tool is Active Directory. In a cloud computing environment, however, other IAM (Identity and Access Management) tools offer additional features and functions. In addition to specific software applications and plug-ins, one may also contract for IDaaS (Identity as a Service).

- IBM Security Identity Management Suite
- Microsoft On Premises IAM
- NetIQ Identity & Access Management
- Okta IDaaS
- Oracle Identity and Access Management Cloud Service
- Ping Identity offers both a product as well as service
  - PingAccess Server
  - PingAccess Cloud

5.2 *Application Technology Platforms*

Referencing candidate applications from Section 2, Technical Operations Applications Assessment, beginning on page 6, this subsection explores technology hardware and/or software requirements to enable those applications. Technologies described herein leverage infrastructure described above in subsection 5.1, beginning page 32.

Each of the following subsections correlates with candidate applications detailed in subsections 2.1 through 2.7, beginning on page 6.

5.2.1 Data Processing

Four operational scenarios are identified for Data Processing, in Section 2.1, beginning on page 6.

- stream data to shore in real-time
- bulk data transfer to shore
- shoreside personnel process shipboard data in situ
- pre-process data subset shipboard, to send ashore for further processing

Each of the data processing scenarios listed above is dependent upon a set of technical requirements that need to be fulfilled to enable it. A primary consideration for each scenario is data networking requirements, which are explored in the following subsection. Other technical requirements are also identified and explored in the ensuing subsection, titled Enabling Technologies, below on page 42.

Data Networking Requirements

Data networking requirements for the four data processing scenarios are differentiated by several primary variables:

- network bandwidth – determined by data volume
- network reliability – dependent upon operational workflow
- time sensitivity – determined by operational workflow requirements
- synchronous / asynchronous activity – determined by operational workflow
- network symmetry / asymmetry – determined by data volume and operational workflow

The following subsections each focus on one of the four data processing scenarios, characterizing time sensitivity, network bandwidth, reliability, synchrony and symmetry requirements.

Real-Time Data Streaming

Streaming in real time is by definition a synchronous process and requires high-reliability network connectivity to ensure an uninterrupted data flow.

Data volume is dependent upon the nature of source data. Applications revealed during this study imply data volume is modest, especially if pre-processed shipboard, as described below.

Streaming data in real-time is highly asymmetrical – data is sent from ship-to-shore. If processed data is returned from shore-to-ship, it is unlikely to be sent as a real-time stream. Rather, processed data would be sent as a bulk transfer, or could be processed in situ, as described below.

Bulk Data Transfer

Being an asynchronous process, bulk data transfer is forgiving of network reliability. While tolerant of interruptions, the network needs to be available enough to support whatever volume of data needs to be delivered in whatever time constraints are specified. File transfer software also needs to support resuming delivery of an interrupted file transfer.

Data volume depends upon the nature of source data – e.g. if multibeam data, then could be very large files. In addition to volume of source data delivered from ship-to-shore, another important consideration is volume of processed data returned from shore-to-ship.

The level of network symmetry / asymmetry depends upon initial data volume sent from ship-to-shore versus processed data volume that is returned from shore-to-ship. Processed data is presumably a smaller volume than source data, although evaluations imply processed data volume can vary significantly by application. Therefore, network requirements are presumed to be asymmetrical, with more traffic from ship-to-shore, although the differential will vary by application.

In Situ Data Processing via Telecommunications

In situ processing involves shoreside end-users using their local computer to access and interact with shipboard server(s). The interactive nature of this process requires synchronous network connections. Network reliability, therefore, is crucial in this operational model, as shoreside end-users are dependent upon connections facilitated by shipboard server(s).

Data volume is a potentially confusing term in this operational model, as source data remains in shipboard systems without being transferred to shore. Data volume in this case is related to network traffic required to support shoreside users connecting to/from shipboard server(s) – which, despite being graphics-intensive, is anticipated to be low compared to the bandwidth needed for file transfers.

Network connections to/from shipboard server(s) are inherently symmetrical. Depending upon how many end-users will connect to shipboard systems, adding a shipboard server may be recommended.

Pre-Process Data Shipboard

Data volume reduction is identified as a precursor to maximizing efficiencies of data processing applications described in previous subsections. This pre-processing is done shipboard, without connecting to shoreside systems, so requires no ship to/from shore network bandwidth. Software application(s) run locally shipboard can automate some or all pre-processing tasks.

Another data volume reduction opportunity is to subsample data streams. This is described above, in Develop Apps to Use Lower Bandwidth, on page 36.

Enabling Technologies

Requirements noted in Section 2.1, Data Processing, beginning on page 6, include voice and email utility communication tools. These are needed to coordinate efforts, including to provide confirmation messages.

See below in subsection 5.2.7, Productivity Applications, page 49, for a more complete description of these and other utility tools.

5.2.2 Remote Configuration Diagnostics Support

This candidate application is focused on IT administrative functions, as described in Section 2.2, Remote IT and Instrumentation Support, beginning on page 8. Technologies required to support this application align directly with tools detailed above in subsection 5.1.4, IT Administration, beginning on page 38.

Given IT administration tools have already been thoroughly described earlier in this Section, these descriptions will not be repeated here. Rather, only a description of other enabling technologies is included.

Enabling Technologies

Voice and email are identified as useful communication tools to request technical operations services, and for follow-up responses. To provide more advanced support, the ability to share a computer screen is also desirable, which is provided for among the manifold IT administration tools described earlier.

See below in subsection 5.2.7, Productivity Applications, page 49, for a more complete description of these and other utility tools.

5.2.3 Collaborative Troubleshooting

As described in Section 2.3 on page 11, Collaborative Troubleshooting is facilitated with bi-directional, real-time communications. Screen sharing, video chat, voice communications, as well as some IT administration tools, such as remote desktop, are all potentially valuable for collaborations.

Collaborations are mostly synchronous, real time activities. Symmetry will vary by incident, with more traffic from ship-to-shore in cases where shipboard evidence needs to be shared with shoreside personnel, and more traffic from shore-to-ship in cases where shoreside demonstrations will be shared with shipboard personnel.

Bandwidth requirements will vary depending upon what medium is employed for a given collaboration. Video streaming has a potential for requiring the most bandwidth, although electing to use lower frame rates or possibly using still images rather than moving video offer opportunities for efficiencies.

Some data files may need to be transferred asynchronously to be used as evidence in collaborative troubleshooting. Requirements for such transfers would be the same as those noted above in subsection 5.2.1, Data Processing.

5.2.4 Custom Software Development

Section 2.4 on page 11, details Custom Software Development processes, which include a combination of collaboration and data transfers.

Shipboard personnel may communicate about a software anomaly, or request new functionality. These communications may be fulfilled asynchronously via email, or may require synchronous interaction, via voice, screen sharing or other collaboration tools. IT administration tools could also be useful in cases where software anomalies are being investigated.

Network dynamics for this custom software development application, therefore, are analogous to those for whichever interaction methods are employed, including: Collaborative Troubleshooting, subsection 5.2.3; and Remote Configuration Diagnostics Support, subsection 5.2.2.

Two software implementation options are detailed in Section 2.4 – shoreside development with code drop to shipboard systems, and in situ code modification. Processes associated with shoreside development with code drop are comparable to data transfer options described above in subsection 5.2.1. In situ code modification would operate the same as In Situ Data Processing via Telecommunications described above on page 42.

5.2.5 Situational Awareness

Section 2.5, beginning on page 12, describes Situational Awareness requirements. Multiple cameras placed in strategic shipboard and shoreside locations are a significant component of technologies required for this application. A platform for aggregating and viewing images from those cameras is another component.

In addition to cameras, situational awareness involves enabling shoreside personnel to view data displays – location and position information, including navigation data, latitude / longitude, depth, temperature, among others.

Situational awareness is by definition a synchronous application – its utility is predicated on end-users viewing situations in real time. Bandwidth requirements and network traffic symmetry, therefore, are dependent upon several variables, including:

- number of cameras shipboard and shoreside
- camera image quality / resolution
  - color / monochrome
  - video frame size
  - video frame rate
  - interlaced versus progressive scanning
  - video compression
- viewing platform system requirements

Because this is a synchronous application, network reliability will directly affect end-users' abilities to view video streams. The nature of this application is not considered mission-critical, however, so while intermittent network connectivity would interrupt video streams, it would minimally disrupt operations.

Cameras – Quantity and Placement

The number and placement of cameras in shipboard and shoreside venues was not conclusively identified for this evaluation. Interviewees' suggestions range between one ~ four cameras for shipboard, with less certainty about shoreside.

Shipboard camera placement suggestions focused on the control van, laboratories, deck and hangar. Some suggested common spaces might be another location, but many were reticent due to the Big Brother Effect described in 2.5.2, page 12.

Cameras – Image Quality

There is a direct trade-off between bandwidth and image quality – higher image quality requires greater bandwidth. Optimizing camera image quality to satisfy, but not exceed, situational awareness requirements is considered prudent.

Video resolution is often cited as a key consideration in camera image quality. Resolution is a function of a few variables: color / monochrome image; frame size; frame rate; interlace vs. progressive scanning; compression algorithm.

Color / Monochrome Image

Color images require more bandwidth to stream than do monochrome images. Some interviewees suggested monochrome images would be sufficient for this situational awareness application. Others thought specifying color would allow for interactions that go beyond simple awareness, and involve collaboration where color might be a crucial component of that interaction.

Frame Size

When describing image 'resolution', most people are referring to frame size, which is specified as a rectangular pixel array defined as:

number of pixels per line (width) x number of vertical lines (height)

Frame size is calculated as an area, so proportional modifications to vertical lines and pixels per line of a value x yield x^2 changes in frame size. For example:

- a frame size of 640 pixels per line x 480 lines = 307,200 pixels
- if reducing both measures proportionally by ½, then the resulting frame is 320 pixels per line x 240 lines = 76,800 pixels, or ¼ of the original

Given the nature of this situational awareness application, choosing a smaller frame size is likely a reasonable trade-off to gain bandwidth efficiencies.

Frame Rate

While frame size is often treated as synonymous with resolution, frame rate is an equally important factor affecting resolution. Video frame rates are specified in a number of frames per second, and range from a single frame per second up to thousands of frames per second. A typical video frame rate for most applications is either 30 or 60 frames per second.

Lower frame rates require less bandwidth for streaming, and less storage for recording applications, but come with a trade-off of stuttered motion artifacts. Another advantage of lower frame rates is they can enable operations in lower-light environments, but this comes with a trade off of blurred images from moving objects.

For this situational awareness application, lower frame rates would seem appropriate, possibly on the order of 5 frames per second.

Interlace vs. Progressive Scanning

Video frames can be scanned in two alternating fields that are interlaced, or as one progressive frame. When calculating total payload, all else being equal for a given frame size and a given frame rate, progressive scanning requires double the bandwidth compared to interlace scanning.

While the above may seem like a stunning difference in bandwidth requirements, it is important to note that image quality is a function of the combination of the three variables – frame size, frame rate and scanning. And choices among these three variables are optimized to achieve a desired goal.

For this situational awareness application, a small frame size, with a low frame rate and interlaced scanning would seem appropriate.

Video Compression

Streaming video involves encoding at the source and decoding for viewing. Encoders include options for compressing video to reduce payload, thereby achieving bandwidth efficiencies. A range of compression options is available, ranging from 'lossless' to 'very lossy'.

Choosing 'lossless' compression yields modest bandwidth efficiencies while retaining exceptionally high quality. Choosing 'very lossy' compression yields greater bandwidth efficiencies, while trading off quality.

Lossless or lossy compression are important considerations for applications where received video will be repurposed. For this situational awareness application, where video is intended only to be viewed, and not used in production, aggressive 'lossy' compression is warranted.

Considering frame size, frame rate, scanning and compression recommendations presented in this subsection, one might reasonably expect to achieve an estimated bandwidth per camera of between 50 ~ 250 kbits/sec.

Viewing Platform

Signals from individual cameras could be sent as independent streams that would allow end-users to select one from among the array to view at a given time. While this might be acceptable for some situations, a more desirable approach for some applications would be to present a multiviewer display of some number of cameras, providing a more comprehensive view.

A camera viewing software platform would provide the multiviewer functionality described above. Often referred to as a VMS (video management system), camera viewing platforms typically feature the ability for each end-user to customize their view from among the cameras available, and to select a single camera for full screen viewing.

These VMS platforms are designed for the surveillance industry, although they find uses in many other applications. End-users access the system as a web application, either through a desktop computer, laptop computer, tablet or smartphone. Although not identified as a requirement for situational awareness, VMS platforms also support recording individual camera streams.

VMS software can be installed on WHOI servers. Many vendors also offer hosted cloud services, which would require camera video streams to be delivered to a hosting location, with shipboard and shoreside end-users connecting to the hosting service for viewing.

When cameras are connected to an IP network and configured properly, they are 'auto discovered' by VMS software – care is advised when configuring a system to prevent unauthorized viewing through auto-discovery. End-user authenticated access is managed through the VMS – by groups and/or per-user.

There are many VMS vendors, some of whom also sell cameras. The following list is a representative sample:

- Aimetis
- Axis Communications
- Cisco Video Surveillance
- Exacq VMS
- Genetec
- March Networks
- Milestone Systems
- On-Net Surveillance Systems

Some VMS vendors offer free small-scale video management platform software. These systems are often full-featured VMS platforms that limit the number of cameras and/or end-user viewing locations. For example, see Milestone XProtect Essential.

Offering a combination of cameras and video management software is sometimes presented by vendors as an advantage. As an incentive, some include free VMS software with the purchase of one or more of their cameras, for example, Axis Companion. Unless this closed architecture is acceptable, however, WHOI may want to select a video management platform based on features and functions, and the ability to support vendor-agnostic cameras.

Data Displays

Interviewees identified requirements for a real-time feed of multiple data streams, e.g. location and position information, including navigation data, latitude / longitude, depth, temperature, among others. All agreed a subset of the full data display in a control van would be sufficient, although quantifying a specific data subset and associated data bandwidth is not included in this study.

A data viewing system similar to one developed at WHOI in 2002 – The 'Virtual Van' – is an example of an implementation of this data display concept. While the Virtual Van was developed for scientific telepresence use, it included all the features required to enable situational awareness. The Virtual Van reportedly has become increasingly difficult to support in recent years, and is slated for eventual replacement. If / when it is replaced, it would seem prudent to specify systems to support situational awareness as a design criterion.

Data feeds are synchronous, highly asymmetrical streams (all data is sent from ship-to-shore). Network reliability, therefore, will directly affect end-users' abilities to view real-time data feeds.

Maps

Interviewees emphasized a need for shipboard and shoreside personnel to share maps that are updated with the latest information gathered during a cruise. Providing a master map data source that is accessible to both shipboard and shoreside personnel, therefore, is considered desirable. To accommodate potential intermittent ship to/from shore connectivity, separate map databases might be provisioned shipboard and shoreside, with automatic synchronizing.

The combination of real-time data displays described above, and updated shared maps between shipboard and shoreside personnel, is considered crucial to enable productive shoreside technical operations.

Voice

Interviewees noted how access to voice communications can fulfill some situational awareness goals. VoIP (voice over Internet Protocol) telephony and/or intercom is considered more than adequate for this application.

Bandwidth requirements for VoIP telephony are less than 100 kbits/sec per line.

5.2.6 Engagement / Outreach / Career Development

Section 2.6 on page 12, describes the Community Outreach / Engagement / Career Development application. It is characterized by real time interactions between shipboard and shoreside personnel, as well as between shoreside people located in separate geographic locations.

Two use-cases are identified: one in Section 3.6.1, Outreach Use Cases, and another in Section 3.6.2, Career Development Use Cases, on page 22.

Outreach Use Cases

Generally targeted to reach school students, the general public or specific communities, outreach attempts to allow interaction with oceanographic personnel. Sometimes, this interaction is between shipboard specialists and shoreside public. Risks of unreliable satellite communications and/or unpredictable availability of shipboard personnel, however, have led some to seek alternatives to ensure scheduled events go smoothly.

One such alternative is to utilize shoreside specialists located in an environment connected via telecommunications network to a ship at sea. Sometimes utilized as a back up to, or sometimes in lieu of, shipboard specialists, this approach minimizes risks by providing a more predictable experience connecting outreach communities to oceanographic specialists.

Shipboard / Shoreside Interactions

Interactions between shipboard and shoreside personnel are real time, synchronous activities. While minor interruptions are likely tolerable, logistics of scheduling and arranging shoreside outreach events suggest these interruptions must be minimized. Network reliability, therefore, is a key factor for successfully fulfilling this application.

Ship to/from shore network traffic is highly asymmetrical for this application. A relatively high quality video stream with audio is sent from ship-to-shore, while a low bandwidth audio stream is returned from shore-to-ship.

Bandwidth requirements will depend largely on quality of the video stream originating from shipboard. This video stream is delivered to shoreside communities who are potentially in large venues, implying a requirement to distribute a relatively high quality image.

Utilizing a methodology similar to that described under Cameras – Image Quality, beginning on page 44, frame size should be a minimum of 1280 pixels x 720 lines, frame rate should be a minimum of 30 frames per second, scanning would ideally be progressive, and moderately aggressive compression should be employed.

Based on the above choices for frame size, frame rate, scanning and compression, one might reasonably expect to achieve an estimated bandwidth for streaming video and audio ship-to-shore of between 1 and 2 Mbits/sec.

Shoreside / Shoreside Interactions

This shoreside to shoreside operational scenario can operate in one of two modes: without shipboard interaction, and with shipboard interaction.

Without Shipboard Interaction

This operational scenario involves only terrestrial networks, so does not impact ship to/from shore networking. All technical requirements are based on WHOI's campus network capabilities, which are not included in the scope of work for this study.

With Shipboard Interaction

Primary interactions with outreach communities will be with specialists located shoreside, which resembles the Without Shipboard Interaction scenario described above. This operational scenario adds a requirement for shipboard interaction, however, which creates a hybrid that incorporates requirements that mirror those described above in Shipboard / Shoreside Interactions.

Shipboard interactions represent the more demanding scenario, which therefore sets the minimum requirements for this application. Accordingly, all of the technical requirements noted above in Shipboard / Shoreside Interactions also apply here.

Career Development Use Cases

For many of the same reasons outlined above under Outreach Use Cases, career development use-cases are likely to benefit from shoreside / shoreside interactions more than they would from shipboard interactions. Interviewees note a primary career development use-case is shoreside personnel mentoring other shoreside personnel.

Some describe examples of shoreside personnel being mentored while engaged in productive activities supporting a mission. Technical requirements for these use cases would mirror those of the specific activities – likely candidates are:

- Data Processing, described in subsection 5.2.1, page 40
- Remote Configuration Diagnostics Support, subsection 5.2.2, page 42
- Collaborative Troubleshooting, subsection 5.2.3, page 43
- Custom Software Development, subsection 5.2.4, page 43

There are no additional technical requirements beyond those referenced in the applications listed above.

5.2.7 Productivity Applications

Section 2.7 on page 13, addresses Productivity Application Access operational requirements. Access to email, project management software, message boards, to-do lists, et al is typically a real time activity.

Supporting mobile devices, and especially personal mobile devices of shipboard personnel, would be an ideal goal. That said, use of personal devices needs to be managed properly to ensure personal use doesn't waste precious bandwidth.

Bandwidth requirements for shipboard access to productivity applications will depend upon specific applications that are included, and how frequently those applications are accessed. Most productivity applications are modestly asymmetrical, with shore-to-ship bandwidth somewhat greater than ship-to-shore.

Most productivity applications consume insignificant bandwidth by shoreside standards. Limited shipboard bandwidth, however, highlights inefficiencies with some applications, and with how end-users access those applications.

Establishing BYOD (bring your own device) policies similar to those commonly employed by corporations, universities and other institutions, is advisable. QoS tools can also be utilized to manage network access. Network segmentation is another possible approach. According to interviewees, some institutions already implement shipboard BYOD usage policies with great success.

Email messages, for example, often include many images that add little or no value to communications, unnecessarily consuming valuable bandwidth. Some institutions require users to set email clients to not load images by default, which allows recipients to manually load images only when necessary. Similarly, users are required to disable automatic operating system updates for laptops and mobile devices, as well as automated synchronizing with cloud services such as Dropbox, to reduce bandwidth consumption.

Another consideration about how applications are used is frequency of automatic polling. For example, one can configure an application to automatically check for new messages on a periodic basis. This is an insignificant issue by shoreside standards, but can have slightly more impact shipboard. Setting an application to check for messages less frequently is one way to reduce network load.

6 Analysis and Recommendations

Referencing findings from telecommunications applications, operations use-cases, personnel and technology options evaluated in Sections 2 through 5, this Section offers quantitative and qualitative analyses along with recommendations. Three primary subsections are included:

- Subsection 6.1, Cost / Benefit Model – explains the inner workings of an Excel® workbook specifically customized to evaluate financial implications associated with multiple scenarios of shipboard / shoreside operations and technology options
- Subsection 6.2, Financial Cost / Benefit Analyses – Multiple Scenarios – presents quantitative financial analyses of multiple scenarios, utilizing a cost / benefit model to compare costs associated with baseline shipboard technical operations with costs for performing some of those technical operations ashore for each scenario
- Subsection 6.3, Recommendations – synthesizes quantitative and qualitative analyses to present recommendations about pursuing implementation of specific scenarios

6.1 Cost / Benefit Model

An Excel® workbook with a 'live' financial model accompanies this report, facilitating evaluation of costs / benefits for an unlimited number of scenarios by modifying one or more variables. This subsection provides an overview of the Excel® workbook, and details the financial model that is at its heart. To obtain a copy, please contact WHOI Principal Investigator, Jonathan Howland, jhowland@whoi.edu, (508) 289-2653.

The model is based on comparative cost / benefit analysis. For a given scenario, baseline costs for shipboard operations are compared with costs for performing those operational tasks shoreside. The resulting net cost / benefit from operations is then summed with quantifiable benefit(s) for each scenario.

Costs for several capital and operating cost categories, as well as quantifiable benefits, are calculated based on variables that are modified to customize a specific scenario. Results are tallied, and then projected for multiple future years. These multiple year results are presented in three views: Annual totals, Cumulative Annual totals, and NPV (net present value) of Cumulative Annual totals in today's dollars.

6.1.1 Excel® Workbook Orientation

A separate Excel® workbook contains a 'live' financial model to allow evaluating multiple scenarios. The workbook is comprised of several worksheets:

- Read Me worksheet – orientation to the workbook, including instructions
- Data worksheet – reference containing data used to facilitate calculations
- Template worksheet – cost / benefit financial model computational engine
- Multiple scenario worksheets – each is a unique cost / benefit scenario evaluation, based on copying the Template worksheet, then customizing assumptions on each worksheet to reflect a unique scenario

Of the worksheets listed above, the computational engine contained in the Template – and, by extension, the multiple scenario worksheets – deserves a more in-depth explanation. Each of these worksheets containing the cost / benefit model computational engine is divided into four sections:

- Assumptions
- Summary Results
- Cost / Benefit Calculations
- Lookup Tables

6.1.2 Assumptions

At the top of each cost / benefit scenario worksheet is an 'Assumptions' section. Variables in this section are intended to be customized to reflect unique criteria associated with each scenario being evaluated. Varying these values for each scenario enables one to compare costs / benefits of multiple scenarios.

The model allows entering values only in cells specifically identified as variables, which are shaded in light yellow. Selecting a cell will reveal guidance for entering valid data – see the 'ReadMe' worksheet for additional data entry guidance. There are also two dropdown menus for selecting satellite communications efficiency.

The following subsections describe the several variables categories contained in the Assumptions section:

- Global Variables
- Personnel Costs
- Satellite Bandwidth
- Capital Equipment
- Third-Party Services (non-satellite)
- Quantifiable Annual Benefits / Disadvantages

Global Variables

Located in the top left portion of the Assumptions section, there are six categories of global variables:

- Financial Multipliers
- HiSeasNet Bandwidth
- Implementation Timeline
- HiSeasNet Ship Days
- WHOI Annual Ship Days & Missions
- Systems Integration

Each of the above categories includes one or more variables, which are described below. These global variables are used in calculations throughout the cost / benefit model.

Financial Multipliers

Financial Interest Rate (used for NPV)

This field is required to facilitate NPV calculations. If the field is left blank, inflation / 'time value of money' will not be factored into NPV cost calculations – all results will show values in future year dollars rather than normalizing results to display values in today's dollars.

Annual Operating Cost / Benefit (de)escalator (non-satellite)

Two separate variables are included in the model to account for annual cost inflation / deflation. This variable applies to all costs except satellite bandwidth, which has a unique variable. This variable also applies to Quantifiable Benefits / Disadvantages, described below, on page 59.

Annual Satellite Bandwidth (de)escalator

Two separate variables are included in the model to account for annual cost inflation / deflation. This variable applies only to satellite bandwidth costs. A separate variable for annual inflation / deflation for all other costs is described above.

Fleetwide Ship Days

Caution is advised when modifying values in these fields. Pre-populated values are based on historical data from HiSeasNet. Unless revised confirmed data is available, use 1607 for C-band, and 750 for Ku-band ship days.

Annual Fleetwide C-band Ship Days

This field is required if any C-band operations are intended to be included in cost calculations. Enter an estimated number of ship days operating with C-band satellite communications during a calendar year.

This variable is used to estimate daily rates for C-band satellite service. Specifying more ship days results in spreading costs across more ships, implying lower day rates. Conversely, specifying fewer ship days results in spreading costs among fewer ships, implying higher day rates.

Ship days can also impact bandwidth availability, and by extension, the amount of bandwidth a satellite service provider would need to contract for. The model estimates bandwidth requirements based on C-band ship days, contracted bandwidth and bandwidth per ship, which is specified in the Satellite Bandwidth category of the Assumptions. The model then estimates cost impacts from any associated increase or decrease.

If left blank, zero C-band ship days will be assumed in cost calculations.

Annual Ku-band Ship Days

This field is required if any Ku-band operations are intended to be included in cost calculations. Enter an estimate of a number of days operating with Ku-band satellite communications during a calendar year.

As with future C-band ship days described above, this variable is used to estimate daily rates for Ku-band satellite service. Similar to C-band ship days, there is an inverse relationship between estimated ship days and day rates. Also, as with C-band ship days, the model estimates a satellite service provider's bandwidth requirements based on Ku-band ship days, contracted bandwidth and Ku-band bandwidth per ship, and then estimates cost impacts for any associated increase or decrease.

If left blank, zero Ku-band ship days will be assumed in calculations.

Fleetwide Bandwidth

Annual Contracted C-band Bandwidth / Footprint

This is a required field. The value in this field establishes a baseline bandwidth that forms the basis for C-band day rates charged by a satellite service provider. The bandwidth value entered here is designated in MHz.

Note MHz is not the same as Mbits/sec, which is how shipboard bandwidth is designated, as described below in Bandwidth per Ship, on page 57.

Annual Contracted Ku-band Bandwidth

This is a required field. The value in this field establishes a baseline bandwidth used in calculations to set a satellite service provider's Ku-band day rates. Similar to C-band, this bandwidth is designated in MHz.

Annual Ship Days and Missions – WHOI

Three categories are included for entering annual ship days and missions:

- Long-Transit Missions – assumed to utilize C-band satellite
- Short-Transit Missions – assumed to utilize Ku-band satellite
- RSN (Regional Scale Node) Missions – assumed to utilize Ku-band satellite

The following subsections describe entries under each of the above categories.

Typical Total Missions per Year

Enter a number of missions WHOI anticipates for the year. This value is used to calculate mission-based costs.

If left blank or set to zero, the model will ignore all other related settings in the Assumptions section, and associated operating costs – including satellite, personnel and travel costs – will be assumed to be zero.

Typical Total Days per Mission

Enter an estimated number of days WHOI ships would typically operate on a mission. This value is multiplied by the number of missions to calculate various operating costs.

If left blank or set to zero, the model will ignore all other related settings in the Assumptions section, and associated operating costs – including satellite, personnel and travel costs – will be assumed to be zero.

Typical Mobilization Days per Mission

Enter an estimated number of mobilization days for a typical mission. This value is used to calculate personnel compensation. If left blank, mobilization days will be assumed to be zero.

Typical Demobilization Days per Mission

Enter an estimated number of demobilization days for a typical mission. This value is used to calculate personnel compensation and satellite bandwidth costs. If left blank, demobilization days will be set to zero.

Typical Transit + Non-Working Days per Mission

Enter an estimated number of transit days + non-working days for a typical mission. This value is used to calculate personnel compensation.

When estimating transit days, be sure to include outbound, return and any interim transit days. Non-working days might include mid-mission layover days in port. If left blank, transit and non-working days will be set to zero.

Travel Costs

Travel Costs per Person, per Mission

Enter an estimate of typical travel costs for one person for a single mission. The model multiplies this estimated travel cost by the number of missions and by the number of personnel per mission.

If left blank, travel costs will be assumed to be zero.

Implementation Timeline

Years Delayed Implementation

This is an optional field that allows one to calculate costs accurately in the event implementation is delayed. The model calculates costs by accruing any inflationary / deflationary financial multipliers during the delayed years, so that the first year of costs accurately reflect costs in that year.

If left blank or set to zero, implementation is assumed to be in year 1. Entering a value of ‘1’ delays implementation by one year to year 2. Entering a value of ‘2’ delays implementation by two years to year 3.

The model accommodates delaying implementation up to 24 years. Valid entries, therefore, are whole numbers from 0 through 24.

Systems Integration

Systems Integration as a % of CapEx

This is an optional field that accounts for systems integration costs as a percentage of CapEx (capital expense). The percentage in this field applies to all capital cost line items.

If left blank or set to zero, the model will assume no integration costs for all capital cost line items.

Personnel Costs – Compensation per Mission

This category includes variables that facilitate comparative evaluations between Shipboard - Baseline (green heading) and Shoreside via Telecommunications (blue heading) personnel costs. Because these are comparative evaluations, entries are required for variables in both the Shipboard and Shoreside sections.

Up to five personnel categories may be entered. The description field in the far left column is optional – if entered, the description will carry through the model to enable easier tracking of calculations. Variables for shipboard and shoreside personnel calculations vary, as described in the following two subsections.

Shipboard

Three checkboxes allow customizing options for which on-site mission activities are included for a given personnel role. Check one or more boxes to add On-Station, Mobilization and/or Demobilization to a personnel role. If any one of the boxes is checked, travel costs are automatically added.

On-Station

Check this box to include activities on-station for a given personnel role. Checking On-Station automatically adds Transit + Non-Working days.

Mobilization

Check this box to include mobilization for a given personnel role.

Demobilization

Check this box to include demobilization for a given personnel role.

Two values are required for each shipboard personnel role one desires to include in the model - number of personnel, and day-rate in dollars.

Number of Shipboard Personnel

This is a required field. Enter the number of shipboard personnel associated with a given role.

Full at-sea Daily Cost / Person

This is a required field. Enter a day-rate for each shipboard personnel associated with a given role.

Shoreside

Similar to Shipboard described above, multiple checkboxes facilitate customizing which activities are included for each shoreside personnel role. Four checkboxes - On-Station, Mobilization, Demobilization and Transit + Non-Work – apply to both shoreside compensation models described below. A fifth checkbox applies only to the Per-Mission compensation scheme, and allows one to include Travel Costs.

On-Station

Check this box to include activities on-station for a given personnel role.

*Note, checking this box has a different effect than that described above on page 54, under Shipboard, where checking On-Station automatically adds Transit + Non-Working days. Checking this box affects only On-Station days. A separate checkbox is included in this section to include Transit + Non-Working days.

Mobilization

Check this box to include mobilization for a given personnel role.

Demobilization

Check this box to include demobilization for a given personnel role.

Transit + Non-Work

Check this box to include Transit + Non-Workdays for a personnel role.

In addition to the customization checkboxes described above, two compensation schemes are available for shoreside personnel: Per-Incident (red heading), and Per-Mission (lavender heading). The model allows for entering data either in one or both compensation schemes – enter data into one scheme if intending to employ only that compensation scheme, or enter into both if intending a hybrid compensation approach.

Per – Incident

Compensation under a per-incident arrangement is structured with a base day-rate plus an hourly rate, with a cap on total daily compensation, all of which are variables in this section. Additional variables for number of personnel and estimated incident hours allow calculating estimated personnel costs for this per-incident compensation model.

Number of Personnel

This is a required field. Enter the number of personnel.

Base Day Rate

This is a required entry. Enter a dollar value.

Hourly Rate

This is a required field. Enter a dollar value for an hourly rate to compensate for each hour worked.

Estimated Incident Hours

This field is required. Enter an estimate of the number of hours per day this person will work, on average, during a mission.

Hours / Day Cap

This field is optional, although entering a value is highly recommended. Enter a number of hours beyond which compensation is capped.

If left blank, or set to zero, the model imposes no daily cap on hours.

Per – Mission

Fields in this section are similar to those in the Per-Incident compensation model described above. This compensation scheme involves a person working full-days, based on a standard workday plus overtime.

Number of Personnel

This is a required field. Enter the number of personnel.

Travel Costs - Checkbox

Check this box to add travel costs for a 'Per Mission' ‘Shoreside Tech Ops via Telecommunications’ worker. A case for adding travel might be to include a person on-site dockside for mobilization, or possibly to cover contractor travel expenses to the shoreside operations center; for example, to WHOI.

Base Day Rate

This is a required entry. Enter a dollar value.

Hourly Rate

This is a required entry. Enter a dollar value for an hourly overtime rate.

Standard Workday

This field is required. Enter a number of hours in a standard workday.

Estimated Actual Hours

This is a required field. Enter an estimate for hours per day a person would work on average. Include the standard workday plus additional hours – e.g. if a standard workday is 8 hours, and it is anticipated one may work an average of 4 additional hours per day, then enter 12.

Hours / Day Cap

This field is optional. To impose a daily cap, enter a value in this field.

Satellite Bandwidth

Entries are required for Shipboard (green heading), and Shoreside (blue heading). Enter target bandwidth in Mbits/sec for C-band and Ku-band – leave blank or enter zero if not intending to utilize one or both.

Satellite Spectral Efficiency

Select the number of Mbits/sec per MHz of satellite bandwidth. This variable is affected by modulation technique, forward error correction, power and other settings. Rather than include options for setting these multiple variables, this Mbits / MHz selection achieves the same purpose, with what is intended as a more intuitive approach to the average user. That said, the typical reader of this report is anticipated to find satellite spectral efficiency to be a foreign concept. If uncertain, select 1.7 Mbits / MHz.

Use dropdown menus to select a desired value - select one each for both Shipboard and Shoreside. Higher values reflect a more efficient utilization of bandwidth, so result in better economies. Lower values would be considered more conservative for the purposes of cost projections.

Guidance from HiSeasNet indicates a value of 1 Mbit / MHz is a minimum value, and 3.4 Mbits / MHz is a best case with current technology systems. Anticipating future technology evolution enabling higher satellite spectral efficiencies, dropdown menus allow selecting values up to 5.0 Mbits / MHz.

If no selection is made, the model uses the minimum 1 Mbit / MHz.

Annual Ship Days and Annual Missions

Two fields – Annual Ship Days, and Annual Missions – are included in both the Shipboard – Baseline and the Shoreside – Tech Ops via Telecommunications categories. These fields are carried over from entries under Global Variables, and are presented here for informational purposes only.

To modify either of these fields, change the value(s) under Annual Ship Days and Missions - WHOI.

Bandwidth per Ship

This variable is used to compare Shipboard – Baseline satellite network costs with Shoreside – Technical Operations via Telecommunications. Enter an estimate for the bandwidth per ship, in Mbits/sec.

If this field is left blank, or set to zero, then bandwidth requirements for the associated footprint are assumed to be nil.

Capital Equipment

Up to five capital equipment categories may be entered in this section. The description field in the far left column is optional – description field entries will carry through the model to enable easier tracking of calculations.

There are two sections for entering capital equipment dollar values: Shipboard Baseline (green heading) and Shoreside via Telecommunications (blue heading). If existing shipboard equipment will require upgrades to maintain shipboard technology, enter them in Shipboard Baseline. If not, then enter capital equipment values only in the Shoreside via Telecommunications category.

Shipboard Technical Operations – Baseline

Capital equipment in the Shipboard category are for existing items that will require future upgrade. No new shipboard capital equipment intended to enable shoreside technical operations should be entered in this section.

Enter a dollar value for the first upgrade – enter a value that is based on today's pricing, the model will calculate future pricing based on financial multiplier variables. Enter the year in which that first upgrade would be implemented. Then enter an upgrade cycle for future upgrades.

First Year Upgrade Cost

This is a required entry for existing shipboard capital equipment intended to be upgraded. Enter a dollar value, based on today's pricing. The model will account for delayed implementation and/or investment year offsets based on financial multipliers in the Global Variables section.

First Year to Implement Upgrade

This is a required entry for any existing shipboard capital equipment intended to be upgraded. Enter a value of '1' for year one, '2' for year two, '3' for year three, and so on. Use this field to set an offset from implementing new technology that is included in the Shoreside category.

Delay of the entire implementation – shipboard and shoreside – is set using the 'years delayed implementation' variable, described in Implementation Timeline, under Global Variables on page 54. The model sums the 'years delayed implementation' and 'first year to implement upgrade' variables when calculating capital costs.

For example, if '0' is entered in the 'years delayed implementation' field under the Global Variables section, and '2' is entered in the 'first year to implement upgrade' field, then the associated capital cost will first appear in year 2 of the model. If 'years delayed implementation' is changed to '1', then capital costs will first appear in year 3 of the model.

Upgrade Cycle

An optional field, enter a value to include future year upgrades after the initial upgrade of existing shipboard capital equipment intended to be upgraded on a cyclical basis. Enter an upgrade cycle in years. If no entry, then only the initial upgrade will be accounted for.

Capital Cost (de)escalator %

This is an optional field. Entering a value for Capital Cost (de)escalator % will account for inflation/deflation for future year upgrades. A positive value implies increased costs in future years when upgrading capital equipment. A negative value implies decreased cost when upgrading.

Training

If anticipating training to enable personnel to utilize and/or support capital equipment, enter values for the number of trainees and the cost per trainee. This will be factored into start-up operating costs, as well as future training according to capital equipment upgrades, in the cost/benefit analysis.

Shoreside Technical Operations

This category is referring to enabling shoreside technical operations, which may include implementing capital equipment shipboard. If there is shipboard capital equipment required to implement shoreside operations, then it should be entered in this Shoreside category.

Initial Capital Equipment Cost

This is a required entry. At a minimum, enter costs for Capital Equipment required to enable shoreside technical operations.

Upgrade Cycle

The model will account for periodic reinvestment if a value is entered in Upgrade Cycle – enter a timeframe in years for how frequently the equipment would need to be updated.

If left blank, or if the value is set to zero, then only the initial capital cost will be accounted for.

Capital Cost (de)escalator %

This is an optional field. Enter a value for Capital Cost (de)escalator % to more accurately account for inflation/deflation. A positive value implies increased costs for upgrading capital equipment in future years. A negative value implies decreased cost when upgrading.

Training

These are optional fields. If training is anticipated, entering a number of trainees and cost per trainee will factor training into start-up costs, as well as when implementing cyclical capital equipment upgrades.

Third-Party Services (non-satellite)

Up to five Third-Party Services categories may be entered in this section. The description field in the far left column is not required, but if entered, it will carry through the model to enable easier tracking of calculations.

There are two sections - Shipboard (green) and Shoreside (blue). At a minimum, enter an annual fee for a given service. If there is a multi-year contract, entering a contract duration will factor into future year calculations.

Quantifiable Annual Benefits / Disadvantages

Up to seven Quantifiable Benefit / Disadvantage categories may be entered in this section. The description field in the far left column is not required, but if entered, it will carry through the model to enable easier tracking of calculations.

Enter an annual dollar value for each benefit. Values will increase at the inflationary rate established by the financial multiplier described in Annual Operating Cost / Benefit (de)escalator (non-satellite), above on page 51.

6.1.3 Summary Results

Immediately below the 'Assumptions' section are summary results of financial analyses based on those assumptions. Values shown in summaries are based on Grand Totals as described in the next section – 6.1.4, Cost / Benefit Calculations.

Summary results for five groups of financial analyses are color-coded as follows:

- green for capital and operating costs for baseline shipboard operations
- blue for capital and operating costs associated with performing some technical operations ashore
- lilac for quantifiable benefits
- light grey for cost / benefit analyses comparing performing some technical operations ashore, to baseline Shipboard operations
- medium grey for breakeven value per berth / per day

Cost Calculations

Summaries – including CapEx and OpEx (operating expense) for implementing Shoreside Operations, as well as for continuing Shipboard Baseline Operations – each show three rows of calculations spanning 24 years. Net costs are calculated in three ways, each showing a different perspective.

- Annual costs
- Cumulative annual costs
- NPV of cumulative annual costs

Annual Costs

Annual cost / benefit is calculated for each of the 24 years. Values for a given year are shown in that year's dollars, based on financial multipliers in Global Variables, under Assumptions – there is no NPV accounting for 'time value of money'.

Net Annual Benefit (Cost) of Shoreside Tech = annual Shipboard Baseline Cost MINUS annual Shoreside Cost PLUS Quantifiable Benefit

Cumulative Annual Costs

Cumulative calculations keep a running total of all results from annual cost calculations by adding previous year totals to current year cost. Values shown in any given year represent a total of all costs from that year plus all previous years. A given year's values are representative of that year's dollars – NPV 'time value of money' is not accounted for.

Net Cumulative Benefit (Cost) of Shoreside Tech = previous year cumulative Benefit (Cost) PLUS current year annual Benefit (Cost)

NPV of Cumulative Annual Costs

NPV calculations are based on cumulative annual costs / benefits, while also accounting for NPV 'time value of money', based on the 'Financial interest rate (used for NPV)' variable under the Financial Multiplier heading in Global Variables in the Assumptions section.

NPV Cumulative Benefit (Cost) of Shoreside Tech = NPV of previous year cumulative Benefit (Cost) PLUS current year annual Benefit (Cost)

Valuing a Berth

As noted below in subsection 6.2.2, Berth Scarcity / Surplus, on page 62, the value of a berth is a significant factor in cost / benefit analyses where there is a scarcity of berths. Three options are outlined for quantifying a berth value – two require assigning a berth value, and one calculates a breakeven berth value.

Discovery for this project revealed widely varying opinions about how to value berths, making this significant variable difficult to quantify. Breakeven analysis is employed, therefore, to determine a per-day berth value to achieve parity between costs to facilitate shoreside technical operations via telecommunications, and cost savings from reduced shipboard technical operations.

Annual Per-Day Berth Value

The formula to determine a breakeven per-day berth value for a given year is:

$$\text{Berth Value} = -1 \times \frac{\text{Net Annual Benefit (Cost) of Shoreside Tech Ops via Telecomm}}{\text{Number of Displaced Shipboard Tech Ops Personnel} \times \text{Total Annual Ship Days}}$$

A positive number breakeven daily per-berth value indicates costs associated with facilitating technical operations via telecommunications, exceed projected cost savings from reducing shipboard technical operations. The calculated daily per-berth value – when applied as a benefit – would achieve breakeven in a given year. Assigning a higher daily per-berth value would result in a net benefit from implementing technical operations via telecommunications, while assigning a lower daily per-berth value would result in a net cost.

A negative number breakeven daily per-berth value indicates that cost savings from reducing shipboard technical operations more than offset costs to facilitate technical operations via telecommunications. A negative number breakeven, therefore, represents a net benefit without needing to consider berth value.

Multiple Year Breakeven Per-Day Berth Valuation

Calculated berth values may vary from year to year, depending upon cyclical costs, e.g. capital equipment expenses. Breakeven analysis based on determining a per-day berth value that would achieve neutral net cost, or cost savings, in a certain timeframe – e.g. three, five or ten years – is often preferable.

See subsection 6.2.6, Scenario Analyses and Interpretations, page 75, for insights about interpreting breakeven per-day berth values.

Cost / Benefit Analyses

Similar to Cost calculations detailed above, cost / benefit analyses include annual, cumulative annual and NPV of cumulative annual costs. These appear at the bottom of the Summary Results section:

- Net Annual Benefit (Cost) of Shoreside Tech Ops
- Net Cumulative Benefit (Cost) of Shoreside Tech Ops
- NPV Cumulative Benefit (Cost) of Shoreside Tech Ops
- Annual Breakeven Berth Value – Value per-Berth / per-Day

The same algebraic logic described above in the Costs section applies to these calculations. A net benefit is shown in black numbers, representing a scenario where costs for baseline Shipboard technical operations exceed costs for performing some technical operations ashore. Conversely, a net cost is shown in red numbers, indicating costs for performing some operations ashore exceed costs for baseline Shipboard technical operations.

More detailed explanations of cost / benefit calculations are presented below in 6.2, Financial Cost / Benefit Analyses – Multiple Scenarios, beginning page 62.

6.1.4 Cost / Benefit Calculations

Values from the Assumptions section are carried to the Cost / Benefit Calculations section. To enable easier navigation, the color-code used in the Assumptions section is also used in the Calculations section – green for Shipboard Baseline, blue for Shoreside and lilac for Quantifiable Benefits. These colors are used to highlight the left column of the model to indicate which category a group of calculations apply to. Subtotals and Totals are similarly highlighted by category.

None of the cells in this Cost / Benefit Calculations section are intended to be modified. Clicking on a cell will reveal a formula, displaying algebraic logic employed to calculate its value, along with variables from the Assumptions section, references to other cells in the Cost / Benefit Calculations section, references to cells on other worksheets and references to look-up tables.

6.1.5 Lookup Tables

Some formulae in the Cost / Benefit Calculations section reference values in these tables. The difference between these tables and those in the 'Data' worksheet are these tables are modified based on variables in the Assumptions section of each scenario worksheet, whereas the 'Data' worksheet includes only static data that is referenced across all scenarios.

6.2 Financial Cost / Benefit Analyses – Multiple Scenarios

Multiple scenarios are developed, based on mixing and matching Applications detailed in Section 2, Use-Cases detailed in Section 3, Personnel Considerations detailed in Section 4 and Technology Options detailed in Section 5. An additional consideration for each scenario is relative demand for shipboard berth space, as described below in subsection 6.2.2, Berth Scarcity / Surplus.

Each scenario is presented in an individual worksheet, where baseline costs are compared to costs / benefits associated with performing technical operations ashore. Costs are forecasted for twenty-four years, showing annual cost comparisons, cumulative annual cost comparisons, as well as NPV comparisons of cumulative annual costs.

6.2.1 Baseline

Each scenario worksheet in the accompanying Excel® workbook includes an 'Assumptions' section, as described above in subsection 6.1.2, beginning page 51. A baseline can be customized for each scenario by entering values into fields located in the Shipboard Baseline group under each cost category.

The baseline does not include any quantifiable benefits, as these are realized only when considering financial impacts of implementing Shoreside technical operations. Accounting for benefits is described below in subsection 6.2.4.

6.2.2 Berth Scarcity / Surplus

One variable in establishing baseline costs is the value of a shipboard berth. As noted in Section 4.1.2, Shipboard Personnel – Direct and Indirect Costs, page 24, WHOI historical compensation data and consultations with NSF yielded a wide range of direct and indirect costs. A significant reason for this wide range is variation in demand for shipboard berths, driven largely by mission objectives, and associated science and technical operations crew staffing requirements.

Berth Scarcity

In situations where demand for shipboard berths exceeds availability, the relative value of a berth will be high, providing a basis for cost comparisons between shipboard and shoreside operations partially based on freeing-up a highly valued commodity. Three options for handling this scenario are:

- include direct personnel compensation plus indirect value of a berth in 'Full at-sea Daily Cost / Person', as described on page 55
- include only direct personnel compensation in 'Full at-sea Daily Cost / Person', and quantify the value of a berth as a quantifiable benefit, as described in Quantifiable Annual Benefits / Disadvantages, on page 59
- calculate a breakeven based on what a berth would need to be valued at for benefits to offset costs associated with tech ops via telecommunications

Berth Surplus

When availability exceeds demand, then a shipboard berth is no longer a highly valued commodity. In this situation, cost / benefit analyses would be based only on direct costs and quantifiable benefits / disadvantages.

6.2.3 Comparative Costs

For each of the scenarios being evaluated, costs associated with performing technical operations ashore are compared with baseline costs described above in subsection 6.2.1. Costs for each scenario are customized by entering values into data fields located under each cost category of the 'Assumptions' section.

Based on values entered in the 'Assumptions' section, capital and operating costs are calculated in the Cost / Benefit Calculations section of each scenario worksheet. Calculations are grouped by category and, for each cost category, costs are calculated for both Shipboard and Shoreside. Following the color code established in the Assumptions section, these shipboard and shoreside subgroups are identified by highlighting a column to the left of a group of rows; green for Shipboard Baseline, and blue for Shoreside.

Grand totals for all costs are shown at the bottom of the Cost / Benefit Calculations section. Calculated separately for Shipboard – Baseline and Shoreside costs, these grand totals are carried to the 'Summary Results' section within a scenario worksheet, as described on page 59.

Comparative costs are calculated by subtracting Shoreside Technical Operations costs from Shipboard – Baseline costs. A positive value implies a net financial benefit, while a negative value implies a net financial cost. This comparative cost calculation alone is not necessarily a complete evaluation, however, as quantifiable benefits are not included.

6.2.4 Benefits and Risks

Having established a baseline, as detailed in subsection, 6.2.1, and compared relative costs, as described in subsection 6.2.3, this subsection focuses on benefits. Two broad categories of benefits are included – quantifiable and non-quantifiable.

Quantifiable Benefits

No Quantifiable Benefits were identified for scenarios included in this evaluation. As described above in Quantifiable Annual Benefits, on page 59, the cost / benefit model is capable of accounting for quantifiable benefits. Therefore, should any be identified in future, the cost / benefit analysis model can be utilized to evaluate financial implications of quantifiable benefit(s).

Quantifiable benefits are summed with results from comparative costs described above in subsection 6.2.3. The total cost / benefit formula based on calculating quantifiable benefits and comparative costs is:

Net Benefit (Cost) of Shoreside Tech = Shipboard Baseline Cost MINUS Shoreside Cost PLUS Quantifiable Benefit

Non-Quantifiable Benefits

Interviewees identified multiple benefits, the dollar value of which is not easily quantifiable. Although not quantifiable, these benefits represent potentially significant value that might reasonably factor into scenario evaluations. This study, however, employs conservative financial evaluation assumptions, which ignore non-quantifiable benefits. Evaluations, therefore, are based solely on quantifiable benefits.

The most significant non-quantifiable benefits are listed in the following subsections.

Avoiding Prematurely Aborted Missions

Interviewees describe situations where mechanical, electrical, electronic and/or software system failures and/or shortcomings can sometimes force a premature end to a mission. Some suggested there have been occasions where shoreside personnel with expertise needed to overcome those failures and/or shortcomings have guided shipboard personnel into effecting a repair.

Implementing Shoreside Technical Operations would enable greater access to shoreside expertise, while also providing more robust tools to facilitate addressing shipboard technical system failures / shortcomings from shore.

See the following Applications descriptions for additional information:

- Instrumentation Support, Section 2.2.1, page 8
- Satellite Communications Systems, Section 2.2.2, page 10
- Collaborative Troubleshooting, Section 2.3, page 11
- Custom Software Development, Section 2.4, page 11

Training / Mentoring / Career Development

Limited shipboard space to accommodate personnel has a direct impact on developing future talent to perform tasks at sea. As documented above in Section 2.6.2, Career Development, page 13, enabling participation through telepresence provides cost-effective field research experience and career development opportunities for the next generation of oceanographic science and technical personnel[12].

Outreach and Engagement

Many interviewees cited the importance of reaching out and engaging with various communities. Education, public relations and development are examples of benefits to be realized. See Section 2.6.1, Outreach and Engagement, page 12.

[12] Van Dover, C. L.; German, C. R.; Yoerger, D. R.; Kaiser, C. L.; Brothers, L. An R/V Okeanos Explorer/AUV Sentry success story (December, 2012)

Increased Productivity At Sea

Two use-cases help to illustrate how technical operations via telecommunications can improve shipboard productivity.

Expedited Data Processing

Many missions involve making decisions about next dive logistics based on information gathered in a previous dive. Expedited shoreside processing of data from previous dives enables prioritizing mission objectives faster than is often feasible with shipboard data processing capacity.

This can result in faster turnarounds as well as establishing more accurate dive plans. See the subsection titled AUV, page 15, and the subsection titled Shipboard Multibeam Data Processing – Proof of Concept, page 17.

Productivity Applications

Interviewees describe how lack of access to familiar applications used daily ashore can be disruptive to productivity while shipboard. This application is described in Section 2.7, Productivity Application Access, page 13.

Leveraging Skilled Personnel Across Multiple Missions

Typically, personnel with specialized skills are scheduled to go to sea for a given mission that would benefit from that particular expertise. Enabling technical operations via telecommunications would allow a given skilled individual to be available to multiple ships that are active concurrently.

Risks and Potential Disadvantages

Along with quantifiable and non-quantifiable benefits enumerated above, it is prudent to acknowledge risks associated with technical operations via telecommunications.

For example, when noting potential benefits of avoiding prematurely aborted missions because of gaining access to special expertise via telecommunications, one should also note the real possibility of needing to abort a mission prematurely as a result of a particular situation requiring a skilled person who is not shipboard, because they are performing their work via telecommunications. And instead of the increased productivity at sea described above, it is possible that delays caused by satellite network interruptions may hinder operations, reducing productivity.

6.2.5 Scenarios

Five scenarios are presented below. Each scenario details findings from comparing costs / benefits of shipboard technical operations with performing those same operations from shore via telecommunications.

Personnel cost assumptions are an average (arithmetic mean) of costs gleaned from a survey of oceanographic research vehicle operators. Other cost assumptions are derived from interviews and research described previously.

Summary cost / benefit analysis results are outlined for each scenario, showing ten years of data – see the cost / benefit model for a full twenty-four years of projections. Additionally, a breakeven berth value to achieve neutral net cost within three years, and sustain cost savings in all future years, is presented to enable easier comparison among scenarios. See subsection 6.2.6, Scenario Analyses and Interpretations, beginning on page 75, for more details about interpreting results.

Scenario 1 – ROV Data Processor; Employee

In this scenario, baseline shipboard technical operations for processing ROV data at sea utilizing a staff employee are compared with processing that same data ashore. Scenario 2, described below on page 68, offers a similar comparison utilizing a shipboard contractor instead of a staff employee.

For an overview about utilizing an employee versus a contractor, see Section 4.4, Rationale for Utilizing Staff versus Contractors, beginning on page 29.

Summary Results

Table 3 below excerpts summary results data from the cost / benefit model scenario 1 worksheet. Calculations reveal that valuing a berth at $116 per day would achieve breakeven within three years in this scenario.

Scenario 1	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Annual Net Benefit (Cost)	-	(31,436)	(5,017)	(4,859)	(4,693)	(4,521)	(25,480)	(4,152)	(3,957)	(3,753)
Cumulative Net Ben (Cost)	-	(31,436)	(36,454)	(41,313)	(46,006)	(50,526)	(76,006)	(80,159)	(84,115)	(87,868)
NPV Cum. Net Ben (Cost)	-	(29,939)	(34,490)	(38,688)	(42,549)	(46,091)	(65,104)	(68,055)	(70,733)	(73,152)

Table 3 Summary Results - Scenario 1

Assumptions

Financial Multipliers

Financial interest rate (used for NPV)	5.0 %
Annual operating cost/ben (de)escalator (non-satellite)	2.0 %
Annual Satellite bandwidth (de)escalator	1.5 %

Fleetwide Ship Days & Satellite Bandwidth

Fleetwide Ship Days	
Annual Fleetwide C-band ship days	1607 days / yr
Annual Fleetwide Ku-band ship days	750 days / yr
Fleetwide Bandwidth	
Annual contracted C-band bandwidth / footprint	1.9 MHz
Annual contracted Ku-band bandwidth	1.8 MHz

Annual Ship Days and Missions

Long-Transit Missions - C-band	
Typical total missions per year	1 cruise / yr
Typical total days per mission	35 days / cruise
Typical mobilization days per mission	4 days / cruise
Typical demobilization days per mission	2 days / cruise
Typical transit + non-working days per mission	9 days / cruise
Short-Transit Missions - Ku-band	
Typical total missions per year	2 cruises / yr
Typical total days per mission	22 days / cruise
Typical mobilization days per mission	4 days / cruise
Typical demobilization days per mission	2 days / cruise
Typical transit + non-working days per mission	4 days / cruise
RSN Missions - Ku-band	
Typical total missions per year	1 cruise / yr
Typical total days per mission	39 days / cruise
Typical mobilization days per mission	4 days / cruise
Typical demobilization days per mission	2 days / cruise
Typical transit + non-working days per mission	9 days / cruise

Travel Costs

Travel costs per person, per mission	$ 1,000 / person

Delayed Implementation

Years delayed implementation	1 year

Systems Integration

Systems Integration as a % of CapEx	18 %

Personnel Costs

Not all personnel cost categories apply to this scenario. Rather than list null entries for categories that do not apply, only those fields with valid data are included in the following table.

Personnel 'A'	
Shipboard Tech Ops / Baseline	
Number of shipboard personnel	1 person
Full at-sea daily cost per person	$ 689 / day
On-Site Mission Activities	• On-Station • Mobilization • Demobilization
Shoreside Tech Ops via Telecommunications	
Per-Incident	none
Per-Mission	
Number of per-mission personnel	1 person
On-Site Mission Activities	• On-Station • Mobilization
Travel	no
Day-rate	$ 314 / day
Personnel 'B'	
Shipboard Tech Ops / Baseline	none
Shoreside Tech Ops via Telecommunications	
Per-Incident	none
Per-Mission	
Number of per-mission personnel	1 person
On-Site Mission Activities	• Mobilization
Travel	yes
Day-rate	$ 627 / day

Satellite Bandwidth

Shipboard Tech Ops / Baseline	
Satellite spectral efficiency	1.7 Mbits / MHz
C-band bandwidth	2 Mbits/sec
Ku-band bandwidth	2 Mbits/sec
Shoreside Tech Ops via Telecommunications	
Satellite spectral efficiency	1.7 Mbits / MHz
C-band bandwidth	5 Mbits/sec
Ku-band bandwidth	5 Mbits/sec

Capital Investment

Capital Equipment 'A'	
Shipboard Tech Ops / Baseline	none
Shoreside Tech Ops via Telecommunications	
Initial capital investment	$ 20,000
Upgrade cycle - years	5 years
Capital cost annual (de)escalator %	(5 %)
Training	
Number of personnel to be trained	1 person
Training cost per person	$ 1,500

Third-Party Services

none

Quantifiable Benefits / Disadvantages

none

Scenario 2 – ROV Data Processor; Contractor

This scenario is similar to Scenario 1, except a contractor replaces a staff employee for processing data at sea. Baseline shipboard technical operations for processing data at sea are compared to processing that same data ashore.

Summary Results

Table 4 excerpts summary data from the cost / benefit model scenario 2 worksheet. Table 8 on page 78 shows that most annual per-day berth values for this scenario are negative – the only scenario with negative berth valuations. See Annual Per-Day Berth Value, page 61, for details about interpreting negative breakeven berth values.

In this scenario, calculations reveal that valuing a berth at $(4) per day would achieve breakeven within three years.

Scenario 2	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Annual Net Benefit (Cost)	-	(16,993)	9,715	10,168	10,634	11,113	(9,533)	12,113	12,634	13,170
Cumulative Net Ben (Cost)	-	(16,993)	(7,278)	2,889	13,523	24,637	15,103	27,216	39,850	53,020
NPV Cum. Net Ben (Cost)	-	(16,184)	(7,372)	1,411	10,159	18,867	11,753	20,362	28,913	37,402

Table 4 Summary Results - Scenario 2

Assumptions

Financial Multipliers

Financial interest rate (used for NPV)	5.0 %
Annual operating cost/ben (de)escalator (non-satellite)	2.0 %
Annual Satellite bandwidth (de)escalator	1.5 %

Fleetwide Ship Days & Satellite Bandwidth

Fleetwide Ship Days	
Annual Fleetwide C-band ship days	1607 days / yr
Annual Fleetwide Ku-band ship days	750 days / yr
Fleetwide Bandwidth	
Annual contracted C-band bandwidth / footprint	1.9 MHz
Annual contracted Ku-band bandwidth	1.8 MHz

Annual Ship Days and Missions

Long-Transit Missions - C-band	
Typical total missions per year	1 cruise / yr
Typical total days per mission	35 days / cruise
Typical mobilization days per mission	4 days / cruise
Typical demobilization days per mission	2 days / cruise
Typical transit + non-working days per mission	9 days / cruise
Short-Transit Missions - Ku-band	
Typical total missions per year	2 cruises / yr
Typical total days per mission	22 days / cruise
Typical mobilization days per mission	4 days / cruise
Typical demobilization days per mission	2 days / cruise
Typical transit + non-working days per mission	4 days / cruise
RSN Missions - Ku-band	
Typical total missions per year	1 cruise / yr
Typical total days per mission	39 days / cruise
Typical mobilization days per mission	4 days / cruise
Typical demobilization days per mission	2 days / cruise
Typical transit + non-working days per mission	9 days / cruise

Travel Costs

Travel costs per person, per mission	$ 1,000 / person

Delayed Implementation

Years delayed implementation	1 year

Systems Integration

Systems Integration as a % of CapEx	18 %

Personnel Costs

Not all personnel cost categories apply to all this scenario. Rather than list null entries for categories that do not apply, only those fields with valid data are included in the following table.

Personnel 'A'	
Shipboard Tech Ops / Baseline	
Number of shipboard personnel	1 person
Full at-sea daily cost per person	$ 809 / day
On-Site Mission Activities	• On-Station • Mobilization • Demobilization
Shoreside Tech Ops via Telecommunications	
Per-Incident	none
Per-Mission	
Number of per-mission personnel	1 person
On-Site Mission Activities	• On-Station • Mobilization
Travel	no
Day-rate	$ 314 / day
Personnel 'B'	
Shipboard Tech Ops / Baseline	none
Shoreside Tech Ops via Telecommunications	
Per-Incident	none
Per-Mission	
Number of per-mission personnel	1 person
On-Site Mission Activities	• Mobilization
Travel	yes
Day-rate	$ 627 / day

Satellite Bandwidth

Shipboard Tech Ops / Baseline	
Satellite spectral efficiency	1.7 Mbits / MHz
C-band bandwidth	2 Mbits/sec
Ku-band bandwidth	2 Mbits/sec
Shoreside Tech Ops via Telecommunications	
Satellite spectral efficiency	1.7 Mbits / MHz
C-band bandwidth	5 Mbits/sec
Ku-band bandwidth	5 Mbits/sec

Capital Investment

Capital Equipment 'A'	
Shipboard Tech Ops / Baseline	none
Shoreside Tech Ops via Telecommunications	
Initial capital investment	$ 20,000
Upgrade cycle - years	5 years
Capital cost annual (de)escalator %	(5 %)
Training	
Number of personnel to be trained	1 person
Training cost per person	$ 1,500

Third-Party Services

none

Quantifiable Benefits / Disadvantages

none

Scenario 3 – HOV with Data Ashore

This scenario adds a data processing function for HOV operations that is not currently supported shipboard. This added functionality adds cost, with no offsetting savings from displacing shipboard technical operations.

Summary Results

Table 5 below excerpts summary results data from the cost / benefit model scenario 3 worksheet. Given that this scenario does not displace any current shipboard personnel, berth value is not a factor in this case.

Scenario 3	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Annual Net Benefit (Cost)	-	(81,323)	(55,952)	(56,863)	(57,789)	(58,730)	(80,827)	(60,661)	(61,650)	(62,655)
Cumulative Net Ben (Cost)	-	(81,323)	(137,275)	(194,137)	(251,926)	(310,657)	(391,484)	(452,144)	(513,794)	(576,449)
NPV Cum. Net Ben (Cost)	-	(77,450)	(128,200)	(177,320)	(224,864)	(270,880)	(331,195)	(374,305)	(416,032)	(456,420)

Table 5 Summary Results - Scenario 3

Assumptions

Financial Multipliers

Financial interest rate (used for NPV)	5.0 %
Annual operating cost/ben (de)escalator (non-satellite)	2.0 %
Annual Satellite bandwidth (de)escalator	1.5 %

Fleetwide Ship Days & Satellite Bandwidth

Fleetwide Ship Days	
Annual Fleetwide C-band ship days	1607 days / yr
Annual Fleetwide Ku-band ship days	750 days / yr
Fleetwide Bandwidth	
Annual contracted C-band bandwidth / footprint	1.9 MHz
Annual contracted Ku-band bandwidth	1.8 MHz

Annual Ship Days and Missions

Long-Transit Missions - C-band	
Typical total missions per year	1 cruise / yr
Typical total days per mission	35 days / cruise
Typical mobilization days per mission	4 days / cruise
Typical demobilization days per mission	2 days / cruise
Typical transit + non-working days per mission	9 days / cruise
Short-Transit Missions - Ku-band	
Typical total missions per year	2 cruises / yr
Typical total days per mission	22 days / cruise
Typical mobilization days per mission	4 days / cruise
Typical demobilization days per mission	2 days / cruise
Typical transit + non-working days per mission	4 days / cruise
RSN Missions - Ku-band	
Typical total missions per year	none
Typical total days per mission	none
Typical mobilization days per mission	none
Typical demobilization days per mission	none
Typical transit + non-working days per mission	none

Travel Costs

Travel costs per person, per mission	$ 1,000 / person

Delayed Implementation

Years delayed implementation	1 year

Systems Integration

Systems Integration as a % of CapEx	18 %

Personnel Costs

Not all personnel cost categories apply to this scenario. Rather than list null entries for categories that do not apply, only those fields with valid data are included in the following table.

Personnel 'A'	
Shipboard Tech Ops / Baseline	none
Shoreside Tech Ops via Telecommunications	
Per-Incident	none
Per-Mission	
Number of per-mission personnel	1 person
On-Site Mission Activities	• On-Station
Travel	no
Day-rate	$ 314 / day

Satellite Bandwidth

Shipboard Tech Ops / Baseline	
Satellite spectral efficiency	1.7 Mbits / MHz
C-band bandwidth	2 Mbits/sec
Ku-band bandwidth	2 Mbits/sec
Shoreside Tech Ops via Telecommunications	
Satellite spectral efficiency	1.7 Mbits / MHz
C-band bandwidth	5 Mbits/sec
Ku-band bandwidth	5 Mbits/sec

Capital Investment

Capital Equipment 'A'	
Shipboard Tech Ops / Baseline	none
Shoreside Tech Ops via Telecommunications	
Initial capital investment	$ 20,000
Upgrade cycle - years	5 years
Capital cost annual (de)escalator %	(5 %)
Training	
Number of personnel to be trained	1 person
Training cost per person	$ 1,500

Third-Party Services

none

Quantifiable Benefits / Disadvantages

none

Scenario 4 – ROV; Leave Engineer Ashore

In this scenario, an ROV engineer performs his/her functions from ashore via telecommunications network connection, rather than shipboard. Efforts are anticipated to be limited, so compensation is per-incident, based on an assumed activity of one hour per day.

Summary Results

Table 6 below excerpts summary results data from the cost / benefit model scenario 4 worksheet. Calculations reveal that valuing a berth at $146 per day would achieve breakeven in three years for this scenario.

Scenario 4	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Annual Net Benefit (Cost)	-	(35,014)	(8,667)	(8,582)	(8,491)	(8,394)	(29,430)	(8,182)	(8,067)	(7,945)
Cumulative Net Ben (Cost)	-	(35,014)	(43,682)	(52,263)	(60,754)	(69,147)	(98,578)	(106,760)	(114,826)	(122,771)
NPV Cum. Net Ben (Cost)	-	(33,347)	(41,208)	(48,622)	(55,607)	(62,183)	(84,145)	(89,959)	(95,419)	(100,541)

Table 6 Summary Results - Scenario 4

Assumptions

Financial Multipliers

Financial interest rate (used for NPV)	5.0 %
Annual operating cost/ben (de)escalator (non-satellite)	2.0 %
Annual Satellite bandwidth (de)escalator	1.5 %

Fleetwide Ship Days & Satellite Bandwidth

Fleetwide Ship Days	
Annual Fleetwide C-band ship days	1607 days / yr
Annual Fleetwide Ku-band ship days	750 days / yr
Fleetwide Bandwidth	
Annual contracted C-band bandwidth / footprint	1.9 MHz
Annual contracted Ku-band bandwidth	1.8 MHz

Annual Ship Days and Missions

Long-Transit Missions - C-band	
Typical total missions per year	1 cruise / yr
Typical total days per mission	35 days / cruise
Typical mobilization days per mission	4 days / cruise
Typical demobilization days per mission	2 days / cruise
Typical transit + non-working days per mission	9 days / cruise
Short-Transit Missions - Ku-band	
Typical total missions per year	2 cruises / yr
Typical total days per mission	22 days / cruise
Typical mobilization days per mission	4 days / cruise
Typical demobilization days per mission	2 days / cruise
Typical transit + non-working days per mission	4 days / cruise
RSN Missions - Ku-band	
Typical total missions per year	1 cruise / yr
Typical total days per mission	39 days / cruise
Typical mobilization days per mission	4 days / cruise
Typical demobilization days per mission	2 days / cruise
Typical transit + non-working days per mission	9 days / cruise

Travel Costs

Travel costs per person, per mission	$ 1,000 / person

Delayed Implementation

Years delayed implementation	1 year

Systems Integration

Systems Integration as a % of CapEx	18 %

Personnel Costs

Not all personnel cost categories apply to this scenario. Rather than list null entries for categories that do not apply, only those fields with valid data are included in the following table.

Personnel 'A'	
Shipboard Tech Ops / Baseline	
Number of shipboard personnel	1 person
Full at-sea daily cost per person	$ 712 / day
On-Site Mission Activities	• On-Station • Mobilization • Demobilization
Shoreside Tech Ops via Telecommunications	
Per-Incident	none
Per-Mission	
Number of per-mission personnel	1 person
On-Site Mission Activities	• Mobilization
Travel	yes
Day-rate	$ 693 / day

Personnel 'B'	
Shipboard Tech Ops / Baseline	none
Shoreside Tech Ops via Telecommunications	
Per-Incident	
Number of per-mission personnel	1 person
On-Site Mission Activities	• On-Station • Mobilization
Base day-rate	$ 275 / day
Hourly rate	$ 100 / hour
Estimated incident hours	1 hour / day
Hours per day cap	10 hours / day
Per-Mission	none

Satellite Bandwidth

Shipboard Tech Ops / Baseline	
Satellite spectral efficiency	1.7 Mbits / MHz
C-band bandwidth	2 Mbits/sec
Ku-band bandwidth	2 Mbits/sec
Shoreside Tech Ops via Telecommunications	
Satellite spectral efficiency	1.7 Mbits / MHz
C-band bandwidth	5 Mbits/sec
Ku-band bandwidth	5 Mbits/sec

Capital Investment

Capital Equipment 'A'	
Shipboard Tech Ops / Baseline	none
Shoreside Tech Ops via Telecommunications	
Initial capital investment	$ 20,000
Upgrade cycle - years	5 years
Capital cost annual (de)escalator %	(5 %)
Training	
Number of personnel to be trained	1 person
Training cost per person	$ 1,500

Third-Party Services

none

Quantifiable Benefits / Disadvantages

none

Scenario 5 – ROV Data Processor with Monitor

This scenario is similar to Scenario 1, described on page 66, with the added functionality of enabling shoreside personnel to monitor shipboard situational awareness – as described in Section 5.2.5, Situational Awareness, page 43.

Summary Results

Table 7 below excerpts summary results data from the cost / benefit model scenario 5 worksheet. To facilitate multi-camera video streams, satellite bandwidth is increased, which adds significant cost.

While berth value does not factor into situational awareness, it is a factor for data processing, the same as in Scenario 1. In this scenario, calculations reveal that valuing a berth at $1,170 per day would achieve breakeven in three years.

Scenario 5	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Annual Net Benefit (Cost)	-	(158,946)	(134,439)	(136,222)	(138,027)	(139,854)	(162,844)	(143,577)	(145,472)	(147,391)
Cumulative Net Ben (Cost)	-	(158,946)	(293,385)	(429,607)	(567,634)	(707,489)	(870,332)	(1,013,909)	(1,159,381)	(1,306,772)
NPV Cum. Net Ben (Cost)	-	(151,377)	(273,317)	(390,991)	(504,546)	(614,126)	(735,642)	(837,680)	(936,141)	(1,031,151)

Table 7 Summary Results - Scenario 5

Assumptions

Financial Multipliers

Financial interest rate (used for NPV)	5.0 %
Annual operating cost/ben (de)escalator (non-satellite)	2.0 %
Annual Satellite bandwidth (de)escalator	1.5 %

Fleetwide Ship Days & Satellite Bandwidth

Fleetwide Ship Days	
Annual Fleetwide C-band ship days	1607 days / yr
Annual Fleetwide Ku-band ship days	750 days / yr
Fleetwide Bandwidth	
Annual contracted C-band bandwidth / footprint	1.9 MHz
Annual contracted Ku-band bandwidth	1.8 MHz

Annual Ship Days and Missions

Long-Transit Missions - C-band	
Typical total missions per year	1 cruise / yr
Typical total days per mission	35 days / cruise
Typical mobilization days per mission	4 days / cruise
Typical demobilization days per mission	2 days / cruise
Typical transit + non-working days per mission	9 days / cruise
Short-Transit Missions - Ku-band	
Typical total missions per year	2 cruises / yr
Typical total days per mission	22 days / cruise
Typical mobilization days per mission	4 days / cruise
Typical demobilization days per mission	2 days / cruise
Typical transit + non-working days per mission	4 days / cruise
RSN Missions - Ku-band	
Typical total missions per year	1 cruise / yr
Typical total days per mission	39 days / cruise
Typical mobilization days per mission	4 days / cruise
Typical demobilization days per mission	2 days / cruise
Typical transit + non-working days per mission	9 days / cruise

Travel Costs

Travel costs per person, per mission	$ 1,000 / person

Delayed Implementation

Years delayed implementation	1 year

Systems Integration

Systems Integration as a % of CapEx	18 %

Personnel Costs

Not all personnel cost categories apply to this scenario. Therefore, only those fields with valid data are included in the following table.

Personnel 'A'	
Shipboard Tech Ops / Baseline	
Number of shipboard personnel	1 person
Full at-sea daily cost per person	$ 689 / day
On-Site Mission Activities	• On-Station • Mobilization • Demobilization
Shoreside Tech Ops via Telecommunications	
Per-Incident	none
Per-Mission	
Number of per-mission personnel	1 person
On-Site Mission Activities	• On-Station • Mobilization
Travel	no
Day-rate	$ 314 / day

Personnel 'B'	
Shipboard Tech Ops / Baseline	none
Shoreside Tech Ops via Telecommunications	
Per-Incident	none
Per-Mission	
Number of per-mission personnel	1 person
On-Site Mission Activities	• Mobilization
Travel	yes
Day-rate	$ 627 / day

Satellite Bandwidth

Shipboard Tech Ops / Baseline	
Satellite spectral efficiency	1.7 Mbits / MHz
C-band bandwidth	2 Mbits/sec
Ku-band bandwidth	2 Mbits/sec
Shoreside Tech Ops via Telecommunications	
Satellite spectral efficiency	1.7 Mbits / MHz
C-band bandwidth	10 Mbits/sec
Ku-band bandwidth	10 Mbits/sec

Capital Investment

Capital Equipment 'A'	
Shipboard Tech Ops / Baseline	none
Shoreside Tech Ops via Telecommunications	
Initial capital investment	$ 20,000
Upgrade cycle - years	5 years
Capital cost annual (de)escalator %	(5 %)
Training	
Number of personnel to be trained	1 person
Training cost per person	$ 1,500

Third-Party Services

none

Quantifiable Benefits / Disadvantages

none

Evaluating Additional Scenarios

An Excel® workbook – containing the cost / benefit model used to perform analyses for all five scenarios presented above – accompanies this report, allowing one to evaluate an unlimited number of additional scenarios.

6.2.6 Scenario Analyses and Interpretations

The following subsections analyze results from the five scenarios described above. Each scenario calculates a net benefit or cost associated with a specific set of assumptions. While results are presented as precise calculations, they should be treated more as approximations, due to the manifold assumptions that underpin each scenario.

In scenarios 1, 2, 4 and 5, a net benefit / cost is calculated by comparing cost savings from reduced shipboard technical operations, with costs for implementing shoreside technical operations via telecommunications. A net benefit is realized when cost savings from reduced shipboard operations exceed costs associated with implementing shoreside operations. Conversely, a net cost is projected when costs associated with implementing shoreside operations are greater than savings from reduced shipboard operations.

Scenario 3 differs from the other four, as it adds shoreside functionality, with no change in shipboard technical operations. This scenario, therefore, is evaluating how much it would cost to add functionality, without any offsetting cost savings.

Bandwidth Synergies / Economies of Scale

All evaluations in this study are based on current bandwidth fees, and assigning those fees wholly to shoreside technical support for a given scenario. Furthermore, base level fleetwide bandwidth is assumed to remain static.

In practice, technical operations are sometimes deployed alongside telepresence operations supporting science and/or outreach, implying potential synergies in exploiting bandwidth provisioned for both activities – bandwidth costs would then be allocated / shared between technical and telepresence operations.

Also, incremental satellite bandwidth above the basic pooled service level are currently incurred by an individual mission requesting that added bandwidth – see Satellite Bandwidth, page 89. If shoreside technical operations are implemented across multiple ships, fleetwide pooled bandwidth would likely be increased to accommodate, resulting in lower bandwidth costs by virtue of economies of scale.

Neither bandwidth synergies from allocating across operations, nor economies of scale from increased fleetwide bandwidth are factored into scenario evaluations. This approach leads to presenting conservative results, which would otherwise be more favorable if factoring in bandwidth synergies and/or economies of scale.

Cyclical Costs

When interpreting results, it is important to consider effects of cyclical cost variations. Results can fluctuate from year-to-year, based largely on initial capital equipment investments and periodic reinvestments. Annual fluctuations also may result from non-linear operating cost variations, such as multi-year contract terms for third-party services.

No matter the cause of annual fluctuations, the effect becomes especially apparent when trying to compare results between and/or among scenarios. Comparing results for any given year can prove misleading, particularly if capital equipment upgrades are performed on differing reinvestment cycles. Likewise for third-party services with varying contract renewal cycles.

Early / Mid / Late Cycle

Evaluating a given scenario by focusing on results from early in a cycle will accentuate effects of costs associated with initial capital investment and/or new third-party contract fees. Results from later in a cycle will show no capital investment costs, while third-party contract fees will remain consistent from year to year for the duration of a renewal cycle.

Capital Equipment Investment Cycles

Capital investments are characterized by an initial purchase, followed by no costs until a number of years later, as defined by an upgrade cycle. Results from the first year in a cycle, therefore, will show the highest overall costs.

Focusing on results from later in a cycle will show effects from realizing benefits of those investments, which have a moderating effect on total annual costs for a given scenario. Results from the last year of a capital equipment investment cycle will represent benefits realized since initial investment, and show the lowest total annual costs for a given scenario, due to exploiting the full value of an investment over the capital equipment's total life-cycle.

Third-Party Contract Renewal Cycles

Third-party contract renewal cycles manifest as constant year-to-year costs for the duration of a contract renewal cycle, with a step-function change in a renewal year. The magnitude of change is a function of the annual operating cost (de)escalator % and the number of years between renewals.

Contending with Cyclical Fluctuations

The model supports multiple capital equipment line items and third-party contracts, each capable of a different reinvestment / renewal cycle. All of the scenarios described above under subsection 6.2.5, Scenarios, beginning on page 65, include no third-party contracts and only one capital equipment line item, which has one associated reinvestment cycle (five years) that is consistent across all scenarios, making it exceptionally easy to identify cycles.

Identifying cycles becomes more complex in the event one exploits the model's capabilities to evaluate multiple capital equipment line items and/or third-party services contracts, with multiple capital reinvestment / contract renewal cycles.

Summary results for each scenario include three calculations of net benefit (cost): annual, cumulative and NPV of cumulative.

Annual vs. Cumulative

Annual results are most volatile. Cumulative results reduce volatility over multiple years, although do not eliminate it. Cumulative – and by extension, NPV of cumulative – results display more volatility in earlier years, decreasing as costs are accumulated over additional years.

Averaging

Averaging results (calculating an arithmetic mean) for multiple years, could reduce volatility further. As described above under Early / Mid / Late Cycle, however, choosing which years to average can significantly affect results.

Comparing Results Between / Among Scenarios

Individual scenario evaluations detailed above in subsection 6.2.5, Scenarios, beginning on page 65, provide summary results, along with a breakeven per-day berth valuation, excerpted from the cost / benefit model. Table 8, shown below on page 78, aggregates all these results into a single table, for easier reference.

Referencing these summary results, one may use any of several approaches to compare results between / among scenarios, as described below.

Annual Results

Results for individual years vary widely, due to cyclical cost variations. Looking at Table 8, below on page 78, effects of the five-year capital equipment reinvestment cycle are immediately apparent.

Cumulative Annual Results

For a given year, cumulative results sum net benefits (costs) from all previous years, plus results for the year in question. While variations in absolute dollars are the same as in Annual Results, percentage variations are much less.

Table 8 Summary Results Comparison

Scenario 1	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Cost / Benefit Analyses										
Net Annual Benefit (Cost) of Shoreside Tech Ops	-	(31,436)	(5,017)	(4,859)	(4,693)	(4,521)	(25,480)	(4,152)	(3,957)	(3,753)
Net Cumulative Benefit (Cost) of Shoreside Tech Ops	-	(31,436)	(36,454)	(41,313)	(46,006)	(50,526)	(76,006)	(80,159)	(84,115)	(87,868)
NPV Cumulative Benefit (Cost) of Shoreside Tech Ops	-	(29,939)	(34,490)	(38,688)	(42,549)	(46,091)	(65,104)	(68,055)	(70,733)	(73,152)
Calculated Annual Breakeven Berth Value										
Value per Berth / per Day		266	43	41	40	38	216	35	34	32

Scenario 2	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Cost / Benefit Analyses										
Net Annual Benefit (Cost) of Shoreside Tech Ops	-	(16,993)	9,715	10,168	10,634	11,113	(9,533)	12,113	12,634	13,170
Net Cumulative Benefit (Cost) of Shoreside Tech Ops	-	(16,993)	(7,278)	2,889	13,523	24,637	15,103	27,216	39,850	53,020
NPV Cumulative Benefit (Cost) of Shoreside Tech Ops	-	(16,184)	(7,372)	1,411	10,159	18,867	11,753	20,362	28,913	37,402
Calculated Annual Breakeven Berth Value										
Value per Berth / per Day		144	(82)	(86)	(90)	(94)	81	(103)	(107)	(112)

Scenario 3	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Cost / Benefit Analyses										
Net Annual Benefit (Cost) of Shoreside Tech Ops	-	(81,323)	(55,952)	(56,863)	(57,789)	(58,730)	(80,827)	(60,661)	(61,650)	(62,655)
Net Cumulative Benefit (Cost) of Shoreside Tech Ops	-	(81,323)	(137,275)	(194,137)	(251,926)	(310,657)	(391,484)	(452,144)	(513,794)	(576,449)
NPV Cumulative Benefit (Cost) of Shoreside Tech Ops	-	(77,450)	(128,200)	(177,320)	(224,864)	(270,880)	(331,195)	(374,305)	(416,032)	(456,420)
Calculated Annual Breakeven Berth Value										
Value per Berth / per Day										

Scenario 4	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Cost / Benefit Analyses										
Net Annual Benefit (Cost) of Shoreside Tech Ops	-	(35,014)	(8,667)	(8,582)	(8,491)	(8,394)	(29,430)	(8,182)	(8,067)	(7,945)
Net Cumulative Benefit (Cost) of Shoreside Tech Ops	-	(35,014)	(43,682)	(52,263)	(60,754)	(69,147)	(98,578)	(106,760)	(114,826)	(122,771)
NPV Cumulative Benefit (Cost) of Shoreside Tech Ops	-	(33,347)	(41,208)	(48,622)	(55,607)	(62,183)	(84,145)	(89,959)	(95,419)	(100,541)
Calculated Annual Breakeven Berth Value										
Value per Berth / per Day		297	73	73	72	71	249	69	68	67

Scenario 5	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Cost / Benefit Analyses										
Net Annual Benefit (Cost) of Shoreside Tech Ops	-	(158,946)	(134,439)	(136,222)	(138,027)	(139,854)	(162,844)	(143,577)	(145,472)	(147,391)
Net Cumulative Benefit (Cost) of Shoreside Tech Ops	-	(158,946)	(293,385)	(429,607)	(567,634)	(707,489)	(870,332)	(1,013,909)	(1,159,381)	(1,306,772)
NPV Cumulative Benefit (Cost) of Shoreside Tech Ops	-	(151,377)	(273,317)	(390,991)	(504,546)	(614,126)	(735,642)	(837,680)	(936,141)	(1,031,151)
Calculated Annual Breakeven Berth Value										
Value per Berth / per Day		1,347	1,139	1,154	1,170	1,185	1,380	1,217	1,233	1,249

NPV of Cumulative Annual Results

Yearly variations are similar to Cumulative Annual Results, described above on page 77, moderated by discounted future cash-flows based on NPV.

Annual Breakeven Per-Day Berth Valuations

Subsection 6.2.2, Berth Scarcity / Surplus, page 62, notes one option for determining the value of a berth is to calculate a breakeven. Annual breakeven berth valuations fluctuate for the same reasons Annual Results fluctuate, as described above.

Multiple Year Breakeven Per-Day Berth Valuations

While determining a breakeven per-day berth value for a given year is useful, it is common to determine breakeven over a period of years. A typical analysis might determine what it would take to breakeven in one year, three years, five years, or possibly ten years. Just such an analysis is presented in Scenarios 1, 2, 4 and 5, below. Per-day berth valuations resulting from these analyses offer a reasonable proxy for comparing results among scenarios.

Scenarios 1, 2, 4 and 5

Scenarios 1, 2, 4 and 5 are based on similar assumptions, with only four categories of variables differing among the four scenarios:

- shipboard personnel compensation
- shoreside per-mission personnel compensation
- shoreside per-incident personnel compensation
- satellite networking bandwidth

Breakeven Per-Day Berth Valuations

As described above under Multiple Year Breakeven Per-Day Berth Valuations, page 79, breakeven per-day berth values offer a reasonable proxy for comparing scenario results. Valuations shown below in Table 9 – calculated using the 'Goal Seek' function in the 'What-If' section of Excel® 'Data Analysis' tools – represent a per-day berth value that will achieve breakeven for a given scenario in a given year, while sustaining cost savings for all future years.

Breakeven Analysis	Per-Day Berth Value to Achieve Breakeven			
	1 Year	3 Years	5 Years	10 Years
Scenario 1	$261	$116	$102	$80
Scenario 2	$141	$(4)	$(18)	$(40)
Scenario 4	$291	$146	$131	$109
Scenario 5	$1,321	$1,170	$1,149	$1,115

Table 9 Breakeven Per-Day Berth Valuations

As is evident from comparing berth valuations to achieve breakeven in one year, three years, five years and ten years, as shown above in Table 9, per-day berth valuations fall within a relatively narrow range for a given scenario.

Comparing Scenario 1 and Scenario 2

Shipboard

Looking at operating expenses for scenarios 1 and 2, only shipboard personnel compensation differs between them. In scenario 1, it is assumed that a shipboard data processor role is filled by a staff employee, at a daily cost of $689. In scenario 2, that same shipboard data processor role is assumed to be filled by a contractor, at a daily cost of $809.

Considering annual missions and number of days per-mission adds up to 118 days annually, during which a shipboard data processor is working. In year 2 – the first year of operations – personnel cost differences work out to:

118 days x $120 / day x 1.02 annual operating cost escalator = $14,500

Shoreside

In scenarios 1 and 2, there is no difference in shoreside personnel costs. Only shipboard personnel compensation differs between them.

In both scenarios, personnel "B" is engaged dockside for 8 hours per day only during mobilization for both scenarios, and is compensated at the full day-rate. Personnel "A" is assumed to typically work 4 hours per day shoreside for every day a ship is on-station, so is compensated at one half the full day-rate for the equivalent of a half day of work.

The assumption of a 4-hour shoreside workday for Personnel "A" implies this function is less than a full-time role shipboard. To the extent that shipboard personnel performing data processing are not engaged in other productive shipboard activities, scheduling efficiencies enable significant personnel cost savings through the use of shoreside data processing.

This scenario assumes shipboard data processors are not required for other shipboard activities when not processing data. Caution is advised when evaluating additional scenarios, to ensure the full portfolio of responsibilities for potentially displaced shipboard personnel are factored into assumptions.

Breakeven Per-Day Berth Valuation

Scenario 1

Annual per-day berth values in this scenario range from $(1) ~ $261 over a twenty-four year period. As shown in Table 9, above on page 79:

- A $116 per-day berth valuation achieves sustained neutral cost or net benefit in three years.
- An $80 per-day berth valuation achieves sustained neutral cost or net benefit in ten years.

Scenario 2

Table 8, above on page 78, shows annual breakeven berth valuations of less than $0 (negative values) for all but two of the ten years, implying this scenario yields a net benefit, regardless of berth values. See Annual Per-Day Berth Value, page 61, for insights about how to interpret negative valuations.

This scenario yields a cumulative net benefit for all but the first two years included in these analyses – see Table 4, page 68. Table 9, page 79, shows:

- A $(4) per-day berth valuation achieves sustained neutral cost or net benefit in three years.
- A $(40) per-day berth valuation achieves sustained neutral cost or net benefit in ten years.

Scenario 4

Shipboard

This scenario assumes a shipboard ROV Engineer role is filled by a staff employee, at a daily cost of $712.

Shoreside

A combination of Per-Incident and Per-Mission compensation is employed for shoreside personnel in this scenario. Scenario 4 is the only one of the five scenarios evaluated that includes Per-Incident personnel compensation. One person, compensated on a per-incident basis, is anticipated to be active for one-hour per day while a mission is on-station, and during mobilization.

Per-incident compensation terms are:

- base rate = $275 / day
- hourly rate = $100 / hour
- estimated daily incident hours = 1 hour
- hours per day cap = 10 hours

A second person, compensated on a per-mission basis at $693 / day, is engaged dockside only during mobilization.

Breakeven Per-Day Berth Valuation

Annual per-day berth values in this scenario range from $46 ~ $297 over a twenty-four year period. As shown in Table 9, above on page 79:

- A $146 per-day berth valuation achieves sustained neutral cost or net benefit in three years.
- A $109 per-day berth valuation achieves sustained neutral cost or net benefit in ten years.

Scenario 5

This scenario is the same as scenario 1, except for satellite network bandwidth, which is increased to 10 Mbits/sec in this scenario.

Shipboard

As in scenario 1, this scenario assumes a shipboard data processor role is filled by a staff employee, at a daily cost of $689.

Shoreside

As in scenario 1, one person, compensated at $314 per day, is engaged remotely when a mission is operating on-station, as well as during mobilization. This person is assumed to typically work 4 hours per day.

Additionally, a second person, compensated at $627 per day, is engaged dockside only during mobilization.

Satellite Networking Bandwidth

Compared to scenario 1, satellite bandwidth is doubled from 5 Mbits/sec to 10 Mbits/sec in this scenario. A total of 110 days of satellite networking is necessary to support missions annually – 33 days of C-band, plus 77 days of

Ku-band. Table 10 below displays satellite networking bandwidth costs for both C-band and Ku-band:

Satellite Costs	Annual Sat. days	5 Mbits/sec	10 Mbits/sec	Increased $ / day	Increased $ / year
C-band	33 days	$ 406/day	$ 2,628/day	$ 2,222/day	$ 73,324/yr
Ku-band	77 days	$ 305/day	$ 1,671/day	$ 1,366/day	$ 105,189/yr
Total	110 days	$ 335/day	$ 1,958/day	$ 1,623/day	$ 178,513/yr

Table 10 Satellite Networking Bandwidth Cost Comparisons

Breakeven Per-Day Berth Valuation

Annual per-day berth values in this scenario range from $1,139 ~ $1,560 over a twenty-four year period. As shown in Table 9, above on page 79:

- A $1,170 per-day berth valuation achieves sustained neutral cost or net benefit in three years.
- A $1,115 per-day berth valuation achieves sustained neutral cost or net benefit in ten years.

Scenario 3

This scenario differs from the other four, in that it adds shoreside functionality without displacing any shipboard operations. Data processing is assumed to not be supported shipboard in this HOV scenario, so added functionality increases shoreside costs, with no offsetting savings from displacing shipboard technical operations.

Shoreside Personnel Costs

One shoreside person, compensated at $314/day, is engaged when a mission is operating on-station – assumed to be 73 days annually in this scenario. This person is assumed to work 4 hours per day. Total added annual cost, therefore, is:

73 days x $314 / day = $23,000

Because this scenario does not displace any shipboard operations, per-day berth valuation is not applicable.

6.3 Recommendations

This study has evaluated the potential for displacing some shipboard personnel who support multiple categories of shipboard technical operations tasks, by performing some of those tasks from ashore.

Operational requirements gleaned from a discovery process are described in Section 1. Candidate applications are identified in Section 2. Operational use-cases are detailed in Section 3. Personnel considerations and technology options are explored in Section 4 and Section 5, respectively. And cost / benefit financial analyses – based on all of these operational, personnel and technology considerations – are presented in subsections 6.1 and 6.2, above.

As the final section of the report, this Recommendations section is intended to offer guidance that is based on synthesizing operations, personnel, technology and financial evaluations gleaned from the study. The following subsections present several recommendations, each accompanied by a corresponding rationale.

6.3.1 Viable Scenarios

Five scenarios were defined and evaluated for this study. Each scenario is based on a set of operational, technological and financial parameters, intended to be characteristic of a typical mission with similar objectives. Financial cost / benefit analyses for all five scenarios are detailed and interpreted above in subsection 6.2.6, Scenario Analyses and Interpretations, beginning on page 75, so will not be repeated here.

Scenario 2

Recommendation

Implementing technical operations via telecommunications is unconditionally recommended for missions similar to that described in Scenario 2 – ROV Data Processor; Contractor, beginning on page 68.

Rationale

Scenario 2 yields a cumulative net benefit for 22 years of the 24 years included in these analyses, as detailed above under Scenario 2, on page 80. It is the only scenario in this study to show a net yearly benefit without factoring in shipboard berth value.

Scenarios 1 and 4

Recommendation

Implementing technical operations via telecommunications is recommended for missions similar to those described in Scenarios 1 and 4.

Rationale

Per day berth valuations to achieve sustained net neutral cost or net benefit within three years equal $116 and $146 for scenarios 1 and 4, respectively. These relatively low breakeven berth valuations of less than $150 / day might be small enough so as to be considered negligible, especially when considering how results could vary based on potential ranges of values one might assign to assumptions.

Scenario 5

Recommendation

Implementing Scenario 5 is not recommended for circumstances where there is a surplus of shipboard berths, as defined in subsection 6.2.2, Berth Scarcity / Surplus, beginning on page 62.

For circumstances where shipboard berths are scarce, implementing technical operations via telecommunications is recommended for missions similar to those described in Scenario 5 – ROV Data Processor with Monitor, page 73.

Rationale

When there is a surplus of shipboard berths, there is no significant value to be realized from freeing up additional berths by moving some operations to shore. When berths are scarce, however, scenario 5 is potentially viable. Determining whether or not a given scenario is viable then depends upon what value one places on those scarce berths.

Scenario 5 achieves breakeven within three years when berths are valued at $1,170 / day. Anecdotal evidence from interviewees suggests this breakeven berth valuation is well below the estimated value for a shipboard berth, when berths are scarce.

Scenario 3

Recommendation

Implementing technical operations via telecommunications is recommended for missions similar to that described in Scenario 3 – HOV with Data Ashore, beginning on page 70, only if perceived benefits of shoreside data processing equal or exceed associated costs – $23,000 for the unique parameters specified for this scenario.

Rationale

Choosing whether or not to implement Scenario 3 is dependent upon the perceived value of adding shoreside data processing being equal to or greater than associated costs, as described above under Scenario 3, beginning on page 82.

This scenario does not displace shipboard personnel so, unlike other scenarios, it is not possible to calculate a breakeven berth value. Rather, breakeven is determined by calculating total costs to implement shoreside data processing – which equal $23,000 for the unique conditions specified in this scenario.

6.3.2 Establish Policies / Standard Operating Procedures

Shipboard – Bandwidth Usage Policy

Recommendation

Establish shipboard bandwidth usage policies, and implement them consistently across all ships in the UNOLS fleet.

Rationale

Shipboard bandwidth is a scarce resource. It will continue to be a scarce resource, even when additional bandwidth is provisioned for a given mission. Establishing policies that provide a clear procedure for prioritizing access to this limited resource helps to manage expectations for science parties and technical personnel, that will result in a consistent experience across all UNOLS vessels.

Implemented correctly, a bandwidth usage policy will reduce potential confusion about appropriate network access among science party and technical personnel, while also minimizing unintentional network bandwidth misuse.

Shipboard – Initiate Satellite Network Connection During Mobilization

Recommendation

Establishing a satellite network connection during NDSF vehicle mobilization, when a ship is still dockside, is highly recommended.

Rationale

A common observation among interviewees is that initiating satellite communications to support NDSF-specific shipboard operations often presents the greatest challenge in establishing a high-bandwidth ship to/from shore network connection, as described above in Crucial Role During Set-up, on page 28. Once the network is established, however, maintaining that connection is much easier. Adopting a standard operating procedure to initiate shipboard satellite network connections during mobilization, addresses this concern directly.

Shoreside – Full End-to-End Facilities Check During Mobilization

Recommendation

An end-to-end facilities check during mobilization, that confirms all shoreside systems associated with a given mission are functioning properly with corresponding shipboard systems, is highly recommended.

Rationale

Following-on from the recommendation to initiate a satellite network connection during mobilization, the next logical step is to ensure that all systems associated with shoreside support for a given mission are functioning properly, prior to a ship leaving port. This standard operating procedure is intended to address potential technical issues while a ship is dockside, where access to needed resources is presumably easier than when at sea.

6.3.3 Personnel Staffing

Shipboard – Satellite Communications Specialist

Recommendation

Adding a skilled satellite network technician shipboard is not recommended. Rather, two other recommendations are proposed:

- standardize shipboard satellite communications technology, as described below in Standardize Shipboard Technology Infrastructure, on page 87
- establish standard operating procedures to initiate shipboard satellite network connections during mobilization, prior to a mission leaving port; see above, Shipboard – Initiate Satellite Network Connection During Mobilization

Rationale

Shipboard satellite communications technology systems differ among UNOLS vessels. These variations among ships' satellite communications systems present differing operating scenarios to configure and maintain those systems, complicating establishing shoreside support.

This issue was highlighted by those with science via telepresence experience. While acknowledging it is a legitimate concern for complex set-ups common in science via telepresence missions, however, satellite communications networking to support technical operations via telecommunications are more straightforward. See Section 4.3.3, Skilled Satellite Network Technicians, page 28.

Satellite network requirements to facilitate shoreside technical operations are more akin to ship to/from shore satellite network connections commonly utilized on current missions. Provisioning increased bandwidth requires no special skills beyond those required to establish networks with lower bandwidth.

Shoreside – IT Administration

Recommendation

Designating a shoreside person or group to be responsible for coordinating with shipboard IT administration is highly recommended.

Rationale

Shipboard IT networks are essentially an extension of whatever shoreside network they are connected to. Shoreside IT administration personnel, therefore, should be cognizant of the additional network segment presented when a ship is connected to the shoreside / campus network. See Section 5.1.4, IT Administration, beginning on page 38.

Shoreside – On-Demand Distributed Tech Ops Resource Pool

Recommendation

Evaluating the feasibility of establishing a distributed technical operations resource pool across multiple institutions is recommended.

Rationale

Leveraging on-demand access to technical resources across multiple institutions is potentially an efficient approach to gaining access to highly qualified personnel. It is thought to be impractical to implement, primarily because there is no existing administrative framework to compensate personnel. See Section 4.2.2, Shoreside Tech Resource Pool, on page 26.

Evaluating the feasibility of establishing a framework to facilitate an on-demand technical resource pool would appear a worthy endeavor. If it proves practical, then further study might be warranted to confirm such an arrangement would return a net benefit, and to establish operational procedures for allowing end-users to access the resource pool.

6.3.4 Shipboard Technology Infrastructure

Leverage Existing Science via Telepresence Satellite Communications

Recommendation

No modification to shipboard satellite communications systems is recommended.

Rationale

As described in Section 5.1.1, Satellite Network Connectivity – Ship to/from Shore, beginning on page 32, current satellite communications infrastructure designed to support science via telepresence will easily support deploying technical operations via telecommunications. The proposal here is to exploit these satellite communications synergies between science and technical operations.

Bandwidth requirements for most technical operations via telecommunications use-cases are significantly less than for science via telepresence, with the possible exception of Bulk Data Transfer, described in Section 2.1.2, page 7.

Evaluate and Document Shipboard Telecommunications Technology

Recommendation

A thorough evaluation of shipboard technology installed on each vessel in the UNOLS fleet is recommended, with the goal of documenting specific equipment complements and configurations in a comprehensive database, and maintaining the integrity of that database with periodic updates.

Rationale

Anecdotal evidence suggests shipboard telecommunications and data networking infrastructure vary among ships. See 5.1.1, Satellite Network Connectivity – Ship to/from Shore, beginning on page 32, and 5.1.2, Shipboard Network, page 36. These variations among ships complicate supporting technical operations from shore – a situation that can be improved by providing shoreside technical operations personnel with accurate information about shipboard technology systems.

Presuming evaluations of existing shipboard technology systems corroborate anecdotal evidence about variations in communications technology among ships, then documenting the unique technology configuration for each UNOLS vessel is the next logical step to facilitate efficient and effective shoreside technical operations.

Some interviewees note there is already precedent for such a database. Referred to as 'shipchecks', a deck layout for every UNOLS vessel is stored / maintained in Basecamp. This database aids in planning for single control van/dual control van operations aboard all UNOLS vessels. The proposed recommendation here is to extend this concept to shipboard technology infrastructure.

Evaluate and Document Existing Shipboard Data Networks

Recommendation

A thorough evaluation of shipboard data networks on each vessel in the UNOLS fleet is recommended, with the goal of documenting specific equipment complements and configurations in a comprehensive database.

Rationale

The same rationale noted above in the previous recommendation about creating a database of all shipboard telecommunications technology configurations, also applies to this recommendation about shipboard data networks.

Standardize Shipboard Technology Infrastructure

Recommendation

Standardizing shipboard satellite modems across all ships in the UNOLS fleet is recommended only during normal cycle for shipboard upgrades.

Rationale

Standardizing modem technology will simplify remote technical operations when setting-up satellite connections. Satellite modems are a significant capital expense, however, and any potential gain from simplifying satellite communications set-ups are not likely to offset those capital costs.

Waiting until a normal upgrade cycle for replacing modems – whether part of a planned cyclical upgrade, or to take advantage of new modulation efficiencies – would seem prudent. See Section 5.1.1, Satellite Network Connectivity – Ship to/from Shore, beginning on page 32.

6.3.5 Shoreside Technology Infrastructure

Evaluate Shoreside Data Network

Recommendation

Evaluating shoreside data network bandwidth as well as security and administration capabilities is recommended.

Rationale

Successful implementation of shoreside technical operations supporting ships at sea will depend upon adequate network connectivity. This includes shipboard networks, which is discussed above in Section 6.3.4, Shipboard Technology Infrastructure. It also includes the shoreside network the ship will connect into.

Evaluating shoreside networks was beyond the scope of this study, however. Therefore, an evaluation is warranted.

6.3.6 Evaluate Additional Scenarios

The five scenarios included in this study are illustrative, although by no means comprehensive. Additional scenarios may be modeled and evaluated using the Excel® workbook that accompanies this report. Utilizing the workbook, one may better match unique conditions associated with technical operations by modifying assumptions made in the five scenarios evaluated for this study. One may also model and evaluate unlimited additional scenarios.

Guidance for utilizing the Excel® workbook model can be found in subsections 6.1, Cost / Benefit Model, beginning on page 50, and 6.2, Financial Cost / Benefit Analyses – Multiple Scenarios, beginning on page 62. Also, the following subsections highlight effects of key variables used in evaluations, which may be useful to help identify general characteristics of potentially viable scenarios.

Key Variables

Financial Multipliers

Three separate financial multiplier variables are defined in the Excel® workbook model, as described above on page 51.

- Financial interest rate (used for NPV)
- Annual operating cost/ben (de)escalator (non-satellite)
- Annual satellite bandwidth (de)escalator

All five scenarios evaluated for this study are based on the same values for these financial multiplier variables, although they need not have been – these variables may be customized for each scenario. Because of the compounding effect in multiyear calculations, each of these financial multiplier variables can significantly affect cost / benefit calculations.

Annual Ship Days and Missions

All five scenarios evaluated for this study are based on an assumption of 4 missions per year, with ship days ranging from 73 to 110 per year. Generally, costs associated with capital equipment would be best exploited as the number of missions / ship days increases – reflecting economies of scale.

Similarly, economies of scale from increased missions / ship days would be realized for any fixed costs associated with personnel staffing – see subsection 6.3.3, Personnel Staffing, page 85, above.

Satellite Bandwidth – Fleetwide

Two categories for fleetwide bandwidth variables are included in the model – Fleetwide Ship Days / year, and Fleetwide Bandwidth – MHz. Satellite bandwidth costs for all five scenarios evaluated for this study are based on assuming:

- Annual Fleetwide C-band ship days = 1607 days / yr
- Annual Fleetwide Ku-band ship days = 750 days / yr
- Annual Fleetwide C-band bandwidth / footprint = 1.9 MHz
- Annual Fleetwide Ku-band bandwidth = 1.8 MHz

As described above in Fleetwide Ship Days, and Fleetwide Bandwidth, beginning on page 52, a pooling arrangement is used to divide costs for a base level satellite bandwidth among participating UNOLS vessels. This pooling arrangement keeps satellite bandwidth fees relatively low for the base level service.

Increased bandwidth is available to any ship, although supplemental bandwidth fees are based on the full cost being borne by the individual mission requesting that increased bandwidth. See Satellite Bandwidth, below in the next subsection.

Caution is advised when modifying values in these fields. Pre-populated values are derived from historical data supplied by HiSeasNet. Unless revised, confirmed data is available, it is advisable to use the pre-populated values.

Operating Costs

Satellite Bandwidth

Most scenarios call for a modest increase in ship to/from shore bandwidth, with associated operating costs. Some candidate applications could require significant bandwidth increases, with commensurately greater operating costs, as is the case in Scenario 5, as described on page 81.

As described above under Satellite Bandwidth – Fleetwide, bandwidth costs are based on a fixed cost for basic service, plus supplemental fees for additional bandwidth above the basic service. While basic bandwidth is available for a relatively low cost by virtue of the pooling arrangement across the UNOLS fleet, supplemental costs for additional bandwidth are significant.

All scenarios evaluated in this study – except Scenario 5 – are based on an assumption of increasing bandwidth from the basic 2 Mbits/sec, to 5 Mbits/sec. Scenario 5 assumes bandwidth is increased to 10 Mbits/sec.

Scenario 5 is equivalent to Scenario 1, with the only exception being satellite bandwidth assumptions – Scenario 1 is based on 5 Mbits/sec, and Scenario 5 is based on 10 Mbits/sec. This allows a direct comparison to help understand the impact satellite bandwidth has on cost / benefit results, as evidenced by comparing per-day berth valuations shown in Table 9, on page 79:

- Scenario 1 breaks even in three years with a berth valued at $116 / day
- Scenario 5 breaks even in three years with a berth valued at $1,170 / day

Personnel

The Excel® workbook model accompanying this report classifies personnel operating costs into multiple categories, capturing manifold values for shipboard and shoreside personnel. Shoreside personnel are further categorized as per-incident and per-mission. See Personnel Costs – Compensation per Mission, beginning on page 54.

Personnel costs escalate / deescalate at a rate set in the Excel® workbook model, as described under Annual Operating Cost / Benefit (de)escalator (non-satellite), page 51. The compounding effect of this (de)escalator annual multiplier can be significant.

Not all data fields in this section of the model require an entry. That said, personnel costs are likely one of the most significant variables when comparing scenarios, and quantifying more personnel cost variables will result in better cost projections, which in-turn will yield more accurate cost / benefit calculations.

Third-Party Services

None of the scenarios evaluated for this study included third-party services. If there had been any, these third-party services would add operating costs that would escalate / deescalate at a rate set in the Excel® workbook model, as described under Annual Operating Cost / Benefit (de)escalator (non-satellite), page 51.

Because of the annual compounding effect, this (de)escalator multiplier can have a significant impact on cost / benefit calculations.

Quantifiable Benefits / Disadvantages

The Excel® workbook model allows for defining 'Quantifiable Annual Benefits / Disadvantages' which, when combined with annual Shipboard Baseline Cost and annual Shoreside Cost, yields a net cost / benefit value. See Annual Costs, page 60.

When quantifying an annual benefit / disadvantage is not practical, breakeven analysis is a possible alternative. For example, freeing up shipboard berth space was identified by many interviewees as a key potential benefit. Quantifying that benefit, however, was impractical. Breakeven analysis was employed instead, as described in Breakeven Per-Day Berth Valuations, beginning on page 79.

Capital Equipment

In general, scenario evaluations show that no capital investment is required to realize net benefits. That said, there are some situations where a modest capital investment could yield even greater net benefits. See subsection 6.3.4, Shipboard Technology Infrastructure, page 86, and subsection 6.3.5, Shoreside Technology Infrastructure, page 88, above.

When including capital equipment in a scenario, the Excel® workbook model allows establishing a separate Upgrade Cycle as well as a Capital Cost (de)escalator % for each capital equipment line item, as described on page 58. Defining both of these variables for each line item is highly recommended.

Because capital equipment purchases are typically cyclical in nature, one must exercise care when interpreting results, as detailed above under Cyclical Costs, beginning on page 76.

Acronym Glossary

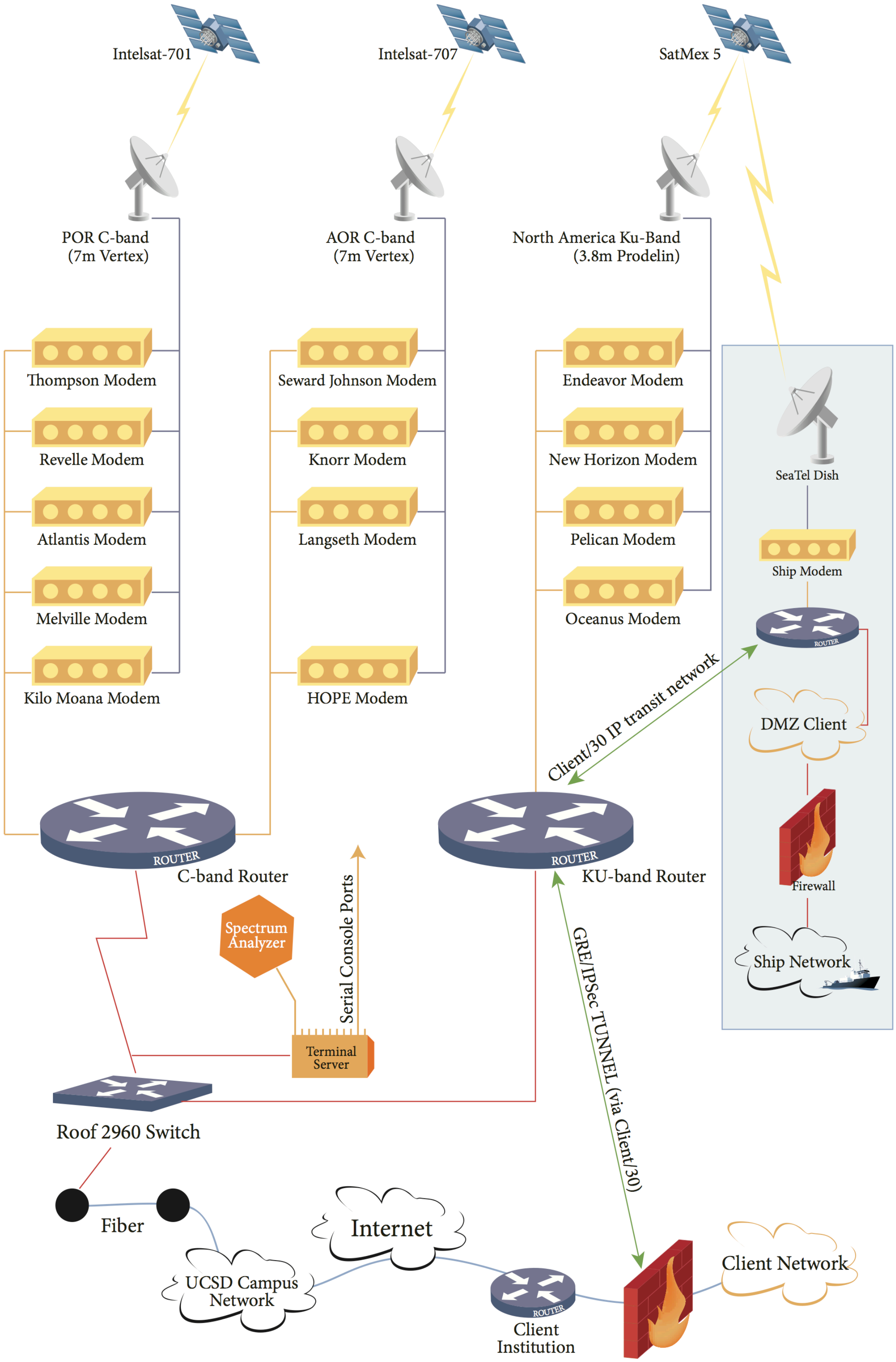
ADCP	Acoustic Doppler Current Profiler
API	Application Program Interface
AUV	Autonomous Underwater Vehicle
BYOD	Bring Your Own Device
CapEx	Capital Expense
CGSN	Coastal & Global Scale Nodes
Codec	Encoder / Decoder
COL	Consortium for Ocean Leadership – http://oceanleadership.org
CRMA	Code Reuse Multiple Access
FEC	Forward Error Correction
FTP	File Transfer Protocol
GridFTP	Open Grid Committee derivative of File Transfer Protocol
HOV	Human Occupied Vehicle
HSN	HighSeasNet
IaaS	Infrastructure as a Service
IAM	Identity and Access Management
IDaaS	Identity as a Service
IM	Instant Messaging
IP	Internet Protocol
iRODS	Integrated Rule-Oriented Data System
ISC	Inner Space Center – http://innerspacecenter.org
LAN	Local Area Network
MTU	Mobile Telepresence Unit
NCEI	National Centers for Environmental Information – https://www.ncei.noaa.gov
NDSF	National Deep Submergence Facility
NOAA	National Oceanic and Atmospheric Administration – http://www.noaa.gov
NPV	Net Present Value
NSF	National Science Foundation – https://nsf.gov
ONR	Office of Naval Research – https://www.onr.navy.mil
OOI	Ocean Observatories Initiative – http://oceanobservatories.org
OpenVDM	Open Vessel Data Management
OpEx	Operating Expense
OSU	Oregon State University – http://oregonstate.edu
PaaS	Platform as a Service
PCMA	Paired Carrier Multiple Access
PEP	Performance Enhancing Proxy
PoP	Point of Presence
PSK	Phase Shift Keying

QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
R2R	Rolling Deck to Repository – http://www.rvdata.us
RCRV	Regional Class Research Vessels
ROV	Remotely Operated Vehicle
RSN	Regional Scale Node
SaaS	Software as a Service
SDK	Software Development Kit
SMS	Short Message Service
SOI	Schmidt Ocean Institute – https://schmidtocean.org
SOP	Standard Operating Procedure
TCP	Transmission Control Protocol
UCSD	University of California at San Diego – http://www.ucsd.edu
UDP	Unicast Datagram Packets
UDT	UDP-based Data Transfer Protocol
UH	University of Hawaii – http://www.hawaii.edu
UNOLS	University-National Oceanographic Laboratory System – https://www.unols.org
VoIP	Voice over Internet Protocol
VSAT	Very Small Aperture Terminal
Wi-Fi	Wireless Fidelity
WCG	Willis Consulting Group – http://willisgroup.com
WHOI	Woods Hole Oceanographic Institution – http://www.whoi.edu

Appendix

Index to Appendices

UCSD / HiSeasNet – Network Diagram



UCSD / HiSeasNet – Bandwidth Testing Results

Lease Resources

Satellite	Beam	Transponder	Polarization	Carrier ID	TX Location	RX Location	TX Freq MHz	RX Freq MHz	Info. Rate (kbps)	Symbol Rate (ksps)	Allocated BW	PEB (MHz)	Modulation	Coding	U/L EIRP dBW	D/L EIRP dBW (B.C.)
Intelsat 23	WHCL /WHCR	WH3C/WH3C	L/R	20371070			6066.30	3841.30	0		5				0	0

Scenario 1: Following carriers to be activated on November 22, 2016 and end on December 02, 2016

Satellite	Beam	Transponder	Polarization	Carrier ID	TX Location	RX Location	TX Freq MHz	RX Freq MHz	Info. Rate (kbps)	Symbol Rate (ksps)	Allocated BW	PEB (MHz)	Modulation	Coding	U/L EIRP dBW	D/L EIRP dBW (B.C.)
Intelsat 23	WHCL /WHCR	WH3C/WH3C	L/R	20402042	SDO-02F3	US8530H3	6066.20	3841.20	4000	4000	4.80	3.54236	QPSK	DIG*FEC=1/2*RS=1/1	62.38	24.80
Intelsat 23	WHCL /WHCR	WH3C/WH3C	L/R	20402039	US8530H3	SDO-02F3	6066.20	3841.20	8000	3999.80013	4.80	1.37785	8PSK	DIG*FEC=2/3*RS=1/1	58.31	20.70

Scenario 2: Following carriers to be activated on December 02, 2016

Satellite	Beam	Transponder	Polarization	Carrier ID	TX Location	RX Location	TX Freq MHz	RX Freq MHz	Info. Rate (kbps)	Symbol Rate (ksps)	Allocated BW	PEB (MHz)	Modulation	Coding	U/L EIRP dBW	D/L EIRP dBW (B.C.)
Intelsat 23	WHCL /WHCR	WH3C/WH3C	L/R	20402270	SDO-02F3	US8530H3	6065.001970	3840.001970	3000	2000	2.40	3.02909	QPSK	DIG*FEC=3/4*RS=1/1	61.70	24.12
Intelsat 23	WHCL /WHCR	WH3C/WH3C	L/R	20402273	US8530H3	SDO-02F3	6067.4025	3842.4025	6000	2000	2.40	1.8591	16PSK	DIG*FEC=3/4*RS=1/1	59.60	22

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16. Abstract (Limit: 200 words)

The National Deep Submergence Facility(NDSF) at the Woods Hole Oceanographic Institution (WHOI) has been actively supporting science and operations via telecommunications and telepresence since the 1990s. Recognizing the potential of telecommunications to save valuable berth space on research vessels by reducing at-sea NDSF manpower requirements, WHOI funded a study investigating the necessary capital investments, costs, and benefits of such an approach. The study identified technical and operational requirements associated with performing some shipboard engineering functions using shoreside personnel. Seven candidate applications were identified to fulfill those requirements, which in-turn led to defining use-cases based on operational processes, along with associated enabling technologies. A rigorous cost/benefit model comparing baseline at-sea operations with telecommunications-augmented operations was developed, and used to analyze five candidate scenarios. A modest increase in typical ship-to-shore bandwidth, and in shoreside manpower requirements would be necessary to support most proposed functions, implying added operational cost. The scenario analyses allowed the use of breakeven analysis to quantify a value achieving net neutral cost by assigning values to shipboard bunks freed up by shifting manpower ashore. The study provides a basis on which operational/engineering use of telecommunications can stand on its own in maximizing the productivity of at-sea deep submergence operations. In conjunction with scientific or outreach use of telepresence, or in the event of reductions in the cost of ship-to-shore bandwidth, the case is even more compelling.

17. Document Analysis a. Descriptors

NDSF
telecommunications
telepresence

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

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