***Project Title:***

# Implementation of Sustainment Technologies for the Ohio Replacement Class and VIRGINIA Class Submarines to Reduce Total Ownership Costs and Increase Operational Availability

**NSRP TIA #2013-449**

***Deliverable:***
Project Results

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## Title

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## Executive Overview

The VIRGINIA Class and OHIO Replacement Class submarines have stringent deployment and refit availability requirements that contribute to the high total ownership costs for these platforms. In order for submarines to meet these requirements in a more cost effective manner, it is proposed to implement an on-board performance and health management/monitoring (PHM) information system to enable condition based maintenance (CBM) and to actively predict fail to sail conditions before they occur. The General Dynamics Electric Boat, Applied Research Laboratory at The Pennsylvania State University (ARL Penn State), and Newport News Shipbuilding project team performed a modified reliability centered maintenance (RCM) based methodology called a 'Degrader Analysis' to determine the optimum maintenance and sustainment methodology and technology solutions for reducing the total ownership cost (TOC) on selected systems or components. The approach could be applied on a larger scale to reduce TOC for the submarine fleet. The effort focused on the design of an on-hull submarine performance and health management system for components/systems common to VIRGINIA and OHIO Replacement Class submarines. Selected Hull, Mechanical and Electrical (HM&E) components will be improved to reduce operation and support costs while increasing operational readiness.

## Contact Information

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Health Management Subject Matter Expert. Penn State ARL responsibilities involved working with GDEB to implement an analytical process (Degrader Analysis) to determine the optimum maintenance and sustainment methodology and technology solution for reducing the total ownership cost of the submarine fleet.

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Newport News acted in a consultant role and provided input on all project Phases/Tasks.

## Description of Methodology

The project team performed a modified RCM based methodology developed by Penn State ARL called a 'Degrader Analysis' to determine the optimum maintenance and sustainment methodology and technology solutions for reducing the TOC on selected systems or components. The degrader analysis identifies the top candidates for health monitoring and concentrates on those subsystems rather than conducting full Failure Modes, Effects and Criticality Analysis' (FMECA) for the entire platform. This methodology is designed to meet requirements of Department of Defense CBM+ initiatives, but is applicable to any complex defense, space, or industrial system.

The degrader analysis uses a four step process that is not intended as a replacement to the RCM process but is a methodology that is conducted before a formal RCM process to provide a general assessment of whether the health management technology and CBM may be financially beneficial for a specific complex system. This is particularly beneficial for systems/platforms that currently do not have health management technology and for which the investment in a full RCM analysis has not yet been justified.

The first step in the degrader analysis consists of identifying the critical submarine components and systems with the most significant maintainability, logistic and reliability issues. Three data sources were used to identify these critical submarine components and systems. The first source includes statistical data for part replacement, maintenance and sustainment; the second is maintainer interviews; and the third is a submarine original equipment manufacturer (OEM)/Lead Integrator questionnaire.

The second step in the degrader analysis was to conduct a RCM based FMECA. The FMECA process was used to identify failure modes with a high probability of occurrence for the components and systems on the degrader list. It also identified a recommended list of sensors that either currently exist on the platform or would need to be added to enable a diagnostic or predictive capability for each degrader system or component.

The third step of the degrader analysis facilitates the design process for implementing PHM and CBM technology for selected submarine systems and components. This analysis involves identifying sensors, monitoring hardware and processes that enable diagnostic and/or predictive monitoring capabilities.

The fourth and final step in the degrader analysis involves conducting a cost benefit analysis (CBA) for the application of the selected sensor technology that will be used to monitor and manage the failure modes identified for the critical components and systems that are common among the maintainability, logistic and reliability issues lists. Through the integration of the FMECA results with the CBA, the minimal set of sensors and associated monitoring system components that provide the broadest diagnostic and predictive coverage with the highest return on investment can be determined.

Follow-on tasks could use the degrader data from this effort or apply this process to other systems to justify the potential implementation of CBM for those systems.

## Resources Needed

The project team implemented an analytical process to determine the optimum maintenance and sustainment methodology and technology solutions for reducing the total ownership cost of the submarine fleet. To implement this process at other shipyards, a team of experts in the areas of platform components/systems, maintenance planning and fleet maintenance data analysis, component failure modes and effects, sensor hardware/data processing, and the cost benefit analysis/business case process is needed. Specific training on machinery monitoring and automation is required. Access to platform operators/maintainers is required for conducting interviews. Software was required to conduct the RCM analysis and the cost analysis. The final performance health monitoring system design/operator interface mockup utilized modeling software by Adobe Creative Cloud, LPC Expresso, and Autodesk 3DS Max. Our team consisted of 13 personnel.

## Evaluation and Analysis Methods

Goals were established to track each of the three phases of the project and metrics were identified to measure the overall success of the project. Phase 1 goals were the ability to identify affordable technology solutions and hardware with high TRL for naval vessel applications, and the ability to integrate/leverage on-going submarine development efforts. The phase 2 goal was the ability to generate three distinctly different Courses-of-Action that meet the metric goals. The phase 3 goal was to identify technology development issues that impact the implementation cost effectiveness. Final project metrics were identified for five areas. Maintenance cost reduction, Sustainment cost reduction and Mean Logistic Delay Time reduction all had a goal of at least a 5% reduction. The payback period had a goal of 1-3 years. The Return on Investment goal was greater than 3.0. The final project evaluation and analysis was completed using the NAVSEA Cost Estimating Handbook for CBM and the NSRP Total Ownership Cost Template (developed by Dr. Matt Tedesco).

## Time Estimate

This project had a one year period-of-performance. A similar time period would be needed for CBM+ to be implemented on another platform as complex as a submarine. This work would not be implemented as-delivered on other components/platforms. A total of 6500 man-hours was required to complete this project.

## Limitations or Constraints

The CBM+ technology solutions may not all be cost effective to implement. Therefore, conducting a thorough technology and trade study to have multiple technology options for each system/component (i.e. sensors, hardware) is required. A solid Cost Benefit Analysis is required to prove the Business Case.

## Major Impacts on Shipyard

Organizational and Cultural Change:

To realize submarine life cycle cost savings, the ship operators, maintenance, and logistic communities will be asked to accept the new maintenance and sustainment paradigm that can be enabled with sensor-based health management and condition-based maintenance. Other DoD organizations have started migrating to a CBM methodology for their aviation and ground combat system assets, but to do so they are working to change the cultural perception of maintenance and sustainment methodologies through training.

Human Resource Functions:
The addition of sensors to monitor component and system performance health will initially impact the submarine crew workload, as the crew will need to learn, operate, and maintain a new health monitoring system or function. This time investment should be offset by a reduction in the performance of shipboard Maintenance Requirement Card (MRC) workload (O-Level Maintenance). The forecasted operational impact is a neutral impact or a slight reduction in workload. Ultimately, because the health monitoring system will be watching and predicting system/component performance the crew can be more focused on performing mission tasks and training, rather than performing routine maintenance on equipment.

## Cost Benefit Analysis/ROI

The quantifiable benefits used for the Cost Benefit Analysis (CBA) included:

- Reduced Misdiagnosis
- Avoiding Catastrophic Failure
- Enable Advanced Maintenance Planning Capability
- Conversion to CBM+ Usage-Based RESET/Overhaul Method
- Conversion to CBM+ Usage Based Preventative Maintenance Checks

The following Course of Action (COA) costs for this CBA included actions with and without additional diagnostic and predictive sensors and processes that include either wired or wireless data transmission:

- COA 0: Baseline - Status Quo
- COA 1: CBM+ with Existing Sensors
- COA 2: CBM+ with Additional Wired Sensors for Advanced Diagnostics/Fault Isolation
- COA 3: CBM+ with Additional Wireless Sensors for Advanced Diagnostics/Fault Isolation
- COA 4: CBM+ with Additional Wired Sensors for Predictive Capability
- COA 5: CBM+ with Additional Wireless Sensors for Predictive Capability

Based on the results of the CBA:

- COA 4 is the recommended COA for implementation of CBM+ capabilities on the upcoming OHIO Replacement Class submarine.
- COA 5 is the recommended COA for implementation of CBM+ capabilities on the VIRGINIA class submarine for both new construction and back fit to existing platforms.

This project used Net Present Value (NPV) and Payback Period as metrics. The NPV/Investment Ratio was 2.3 and the Payback Period was 6.2 years. Details are included in the final report as well as CBA details for both the OHIO Replacement and VIRGINNIA Class submarines.

## Lessons Learned

The identification of the critical platform component/system candidates was a major part of this project. This required a thorough analysis with access to component failure data, the ability to interview component maintainers, and discussions with the OEMs. The project utilized an analytical “Degrader Analysis” process that was previously proven on other military air/land platforms. This thorough analysis of components and the application of the “Degrader Analysis” resulted in nearly unquestionable results. It is also important to include a team member that is extremely knowledgeable with machinery diagnostics and health management system design. The use of a proven CBA model that is accepted in this industry segment is important to ensure credibility.

## Technology Transfer

The strategy the project team utilized for engagement with both Navy and industry stakeholders regarding technology transfer and implementation of the project involved several activities.

- In order to engage the primary stakeholders, this program required a strong working relationship with the U.S. Navy to enable transfer of information to the project analysis team and a transition of the analysis results and project implementation plan back to the Navy.

- The transfer of information to the industry stakeholder community was conducted through the presentation of conference papers. During the project execution, the project team submitted a conference paper and presentation to both the Defense Manufacturing Conference, the IEEE Aerospace Conference, and the Fleet Maintenance and Modernization Symposium (FMMS) that described the analysis process, the general results of the business case assessment, and the system design attributes of this program.

- In an effort to broaden our team capability and stakeholder base we incorporated Huntington Ingalls Industries Newport News Shipbuilding (HII-NNS) into our project team. Their involvement provided subject matter expertise to the analyses and facilitated the direct transfer of analysis results and the health management system design methodology to a key stakeholder in the naval shipbuilding industry.

## Implementation

The team created a follow-on project plan to conduct a proof of concept demonstration activity. The project plan provides details of the proposed system design and the cost of its implementation and execution for a Navy non-shipboard trainer application. This project implementation plan will facilitate the transition of the health management system technology from a concept to a functioning embedded solution. Successful project demonstration on a Navy non-shipboard trainer will then enable shipboard trials aboard a deployed submarine platform, and the eventual technology transition during the detail design phase of the OHIO Replacement submarine.

The critical factor that will lead to the successful implementation of the health management system is to leverage the existing strong working relationship with PEO Submarines and to continually provide useful data and information to them through every step of the analysis and development process. The intent is to educate and guide the primary target audience with a thorough understanding of the health management system design methodology and the advantages/disadvantages of the application of the enabling technologies.

Another critical factor that will lead to the projects' successful transition will be affordability. The benefits gained by machinery performance health monitoring to reduce total ownership cost must have demonstrated cost benefits and return on investment.