Office of Naval Research

Mission Life Prediction
for the
Advanced Amphibious Assault Vehicle

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EXECUTIVE SUMMARY

The Department of the Navy Science and Technology (S&T) Corporate Board selected Total Ownership Cost (TOC) reduction as one of the desired future capabilities worthy of significant near term S&T investment. An Integrated Product Team (IPT) was formed to address this capability. The Total Ownership Cost Future Naval Capability IPT (TOC FNC) selected Reduced Maintenance as its highest priority Enabling Capability (EC). In order to address that EC, a Technical Working Group (TWG) was formed to examine the potential of maintenance technologies to reduce the TOC of DoN weapons systems and infrastructure.

The premise of the working group was one that recognized the compelling need to destroy paradigms that support business as usual. Business as usual, in this case, was defined as acceptance of vast amounts of preventative and corrective maintenance performed by technicians with unlimited numbers of hours to perform those tasks.

Technologies were assessed based on potential contribution in terms of return on investment, increased operational capability and enhanced safety. Additionally, value was assigned to technologies that were likely to improve the quality of life of our Sailors and Marines.

The technical working group gave constant attention to the potential for rapid transition and the potential for a technology to make a significant impact into TOC, readiness, capability, safety or quality of life. What was not desired was an approach that nibbled around the margins or required a long term, steady state investment.

One effort selected by the IPT for funding is Mission Life Prediction for the Advanced Amphibious Assault Vehicle (AAAV). In addition to being an effort that will add considerable value to the platform in terms of cost reduction, readiness and remaining useful life, the S&T project schedule is closely mapped to platform acquisition schedule, which will greatly enhance the likelihood of transition.

Finally, this S&T program will be run as a business. Schedules will be drawn and adhered to and projects will operate within approved budgets. Activities that do not add value will not be supported.

PURPOSE

The Total Ownership Cost (TOC) Future Naval Capability (FNC) has been charged by the DoN S&T Corporate Board with developing an S&T program to enable the reduction in TOC of DoN weapons systems and supporting infrastructure. The TOC IPT evaluated numerous TOC reduction technologies and selected the most promising (in terms of capability and timing) for forwarding to the Corporate Board for approval.

In addition to reducing TOC, these technologies will give operators, maintainers and logisticians to greater visibility into the health of mechanical systems. Along with providing the Operational Commander with the knowledge of the "fight" left in his equipment, the equipment operator will be presented with real time platform status information that is self-updating. The maintainer will have his workload reduced with the elimination of most preventative maintenance tasks in favor of tasks required "on condition" and the logistician will be tasked with providing spares only when needed and the historic build-up of the "iron mountain" will no longer be required.

"Equipment and operational availability will increase with improved maintainability and increased reliability designed into new platforms and equipment…"
USMC Warfighting Concepts for the 21st Century

OVERVIEW

Weapons systems are moving away from the old paradigm that combines preventative and corrective maintenance. A shift toward maintenance on condition permits operators to conduct maintenance only when required and or when operational tempo permits. This shift however, can only be enabled by better, smarter components, subsystems, systems and platforms.

Shifting to Condition Based Maintenance (CBM) is a part of a larger strategy and capability. In terms of equipment, the goal is asset management and that is a concept whereby the operator views his assets as tools of mission accomplishment and not merely as things to fix. The operator uses and sustains his equipment for the sole purpose of optimizing his investment. In short, the operator becomes the dog, not the tail.

The expeditionary nature of the United States Marine Corps requires maximum readiness and equipment reliability with a minimum of supporting infrastructure. The AAAV program manager is charged with meeting the program's TOC objective. The goal of this program is to enable TOC reductions beyond program objective, while enhancing safety and increasing reliability and situational awareness.

The bar for operating and maintaining the AAAV has been set high; the objective A_0 is 0.85, 6 years are planned between engine depot overhauls and all organizational level maintenance is required to be performed with the 14 tools carried onboard the platform.

Technologies developed under this program will help turn these objectives into reality.

THE AAAV

The AAAV is an amphibious tracked vehicle that incorporates a planing hull design with planing appendages, robust actuating systems, a retractable track and a diesel engine that provides 2600HP in the water and 800HP ashore. This design provides for speeds in excess of 25KTs on water and 45KTs on land. The vehicle can transition seamlessly from water to land operations by automatically transferring engine power from waterjets to vehicle tracks as needed.

A typical operational concept will have AAAVs deploying from ships located over the horizon, carrying up to 18 combat-equipped Marines plus crew. The AAAVs will transit to shore where they can maneuver at speeds equivalent to that of the M1A2 main battle tank and with a similar operational range.

PLAYING FIELD

Before setting out to reduce TOC, it is valuable to first determine the "playing field". The playing field is that segment of the platform TOC that can be impacted by the technologies developed under this program.

The objective TOC of the AAAV is $11.2B. The first chart below represents Life Cycle segments comprising AAAV TOC.

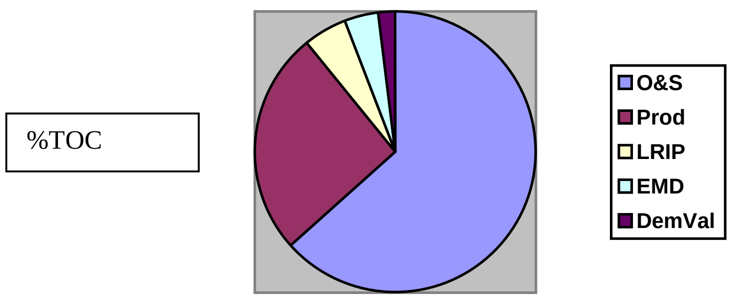

Chart 1

The O&S piece of TOC is 64%, or almost $7.2B, but all of O&S are not in the field. Training ammunition for example, is part of O&S but is not within the scope of this program.

The second chart represents the categories that make up O&S.

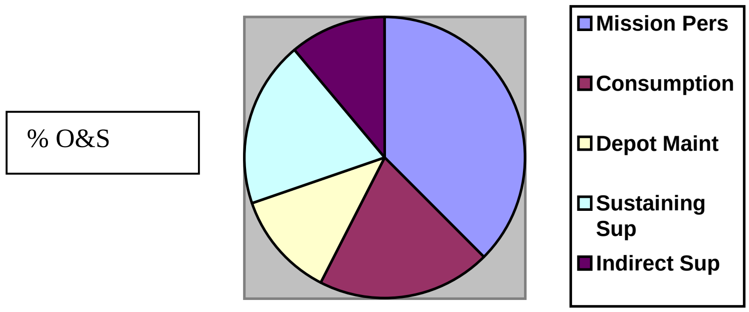

Chart 2

Focusing only on spare parts, depot maintenance and maintenance personnel yields a field equivalent to 32% of O&S or $2.3B (CBM lever). This program will insert technologies into production AAAVs that will reduce the CBM lever and thereby create a cost avoidance.

ASSET MANAGEMENT

We have discussed a shift in the maintenance paradigm toward maintenance upon objective evidence of need or Condition Based Maintenance (CBM). This shift is toward a larger strategy called equipment asset management. Asset management is a concept whereby the operator views his equipment primarily as tools of mission accomplishment, instead of something to be repaired. The operator uses and sustains his equipment for the sole purpose of optimizing his investment.

It is recognized that operational considerations may preclude a tactical commander from optimizing his assets and may require sub-optimization. This program, by enabling mission life prediction, will give the commander the information necessary to make informed decisions based on the "fight" left in his platform or platforms. Development and insertion of technology enablers will provide this information.

Marine Corps doctrine supports this technology insertion, requiring a "….predictive maintenance technology that employs embedded sensors to monitor wear and forecast repair part replacement." USMC Warfighting Concepts for the 21st Century

This technology insertion will enable maintenance to be performed when operational tempo permits.

The technologies selected for insertion will give operators, maintainers and logisticians greater visibility into the health of mechanical systems. Along with providing the Operational Commander the knowledge of the "fight" left in his equipment, the operator will be presented with real time platform status information that is self-updating. The maintainer will have his workload reduced with the elimination of most preventative maintenance tasks in favor of task required “on condition” and the logistician will be tasked with providing spares only when needed and the historic build-up of the “iron mountain” will no longer be required.

This program fully supports USMC doctrinal concepts of the sea base and in-stride logistics.

TECHNOLOGIES

Diagnostic, prognostic and communications technologies are emerging that will enable Mission Life Prediction. MLP will allow host platform managers to adopt an asset management strategy similar to those employed in the private sector. More than maintenance, more than logistics; asset management gives the warfighter part of the basis for sound operational and tactical decisions. Asset management will enable the optimization of assets and occasionally, when circumstances require, permit the warfighter to sub-optimize the use of his assets with full visibility of associated risk.

SENSORS

Smart sensors are becoming commercially available at affordable prices. This has occurred in part due to a combination of investments made by the Office of Naval Research in Condition Based Maintenance enabling technologies. These investments in both the core CBM program and several Dual Use programs have provided the private sector with funding to pursue these sensor technology development for military and commercial use.

These smart sensors are expected to be no larger than $1.0in^3$ and they will incorporate the sensing device, signal processing, self-calibration capability, power source (either by battery or power scavenging) and the ability to communicate up line. The sensors are low weight and low power and will be much more reliable than the hardware they support.

The sensors will sense whatever mechanical feature the customer requires. Typical features are vibration, fluid analysis, thermal and or acoustics.

WIRELESS

This program will strive toward a wireless solution for all applications. The benefits of wireless technology are weight reduction and cost savings in installation and maintenance. Additionally, increased reliability is expected through use of spread spectrum, frequency-hopping technologies.

FLUID ANALYSIS

A comprehensive oil monitoring capability (TOMS or Total Oil Monitoring System) will be developed to detect debris in the lubricant as well as to determine the health of the lubricant. The intention then will be to transmit the information wirelessly within the platform. This technology will be expanded to analyze hydraulic fluid if the customer determines a requirement for that capability.

TOMS will come together via a teaming arrangement involving three individual companies. A COTS oil debris monitor will be joined with a developmental oil condition monitor and the combined device will be equipped with a wireless communications capability. A key challenge inherent will be achieved a sufficient level of ruggedization to withstand the harsh operating environment of a large diesel engine on an amphibious vehicle.

It is recognized that this objective is not trivial. Therefore a systematic approach with objectives of increasing difficulty is planned. The first objective will be to protect the diesel engine of the AAAV (valued at approximately $400,000) by providing warning of immediate, impending catastrophic failure. The second objective will be to assist in diagnosing any engine fault that is presented. The third objective will be to prognosticate a failure in some future time, based upon fluid debris and fluid chemistry.

THEORY OF OPERATION

Selected AAAV components and systems will be outfitted with smart sensors or configured in order to capture data and information from OEM-embedded sensors. These sensors will “sense” mechanical characteristics of monitored systems. These self-calibrating sensors, or component health monitors, will process data and transmit anomalous results upline to the system monitor. The system-level monitor will in turn process data and report to the platform level monitor.

Fluid and mechanical sensor data will be fused and the results subjected to a diagnostic/prognostic engine that will compute Mission Life Prediction.

DATA-SENSOR FUSION

A variety of diverse sensor inputs will be collected by the installed CBM system. The system is best thought of on three levels: component, system and platform. The component sensors will report to a system monitor, which will in turn report to a platform monitor. Diagnostic and prognostic algorithms will be applied at every level to eventually produce a prediction as to remaining useful life.

Derivation of Mission Life Prediction will require, as a baseline, knowledge of when the system is in and out of control. Data gathering in support of this task has already begun as part of an ongoing S&T program. Initial use of this data will enable rudimentary diagnostics at the component, system and platform level. From diagnostics, and given enough operating hours from which to build a knowledge base, the MLP capability will develop. This capability will project the possibility of mission-degrading failure (on monitored equipment) over the next X hours of operation.

It is recognized that this effort is likely to produce increased amounts of data and information. It is also recognized that the DoN has not always excelled in the management and use of maintenance information. In light of this reality, an initiative will be pursued under this program to ensure maintenance information products are available, in a usable format, to those organizations having cognizance over the weapons system or sub-system.

RISK

Risk management strategies will be developed and implemented to address the various types of risk that must be considered

COST

One form of risk that must be managed within this program is cost risk, and there are two types of costs to be considered. First is the risk that the products cannot be completed within the allocated budget and the second is the risk that when the products are delivered, they are too expensive for the program manager to transition.

SCHEDULE

If it appears as if technology development will not proceed as forecast, the customer will be notified at the earliest opportunity. Alternative courses of action will be developed and kept in reserve as a contingency

PERFORMANCE RISK

Substantial risk mitigation investments have been made during the course of the ONR-funded CBM program. Investments in wireless technology, sensor development and fluid analysis have provided a platform from which to enter this program with high expectations of success.

Two MURIs (w/ Georgia Tech and Penn State) have laid extensive groundwork in basic research focused on algorithm development and neural processing.

A DUST program is in place to further development of a CBM open systems architecture. This program teams ONR with PEO Carriers and Caterpillar, Newport News, Boeing, Rockwell, Oceana Sensors Technology and Penn State's Applied Research Lab. Another DUST is in place to advance wireless, smart sensor development. This program teams ONR with Joint Strike Fighter, Oceana Sensors and Penn State.

Despite risk mitigation as articulated above, there is risk within this program. The insertion of emerging technologies in a new weapons system, the required date-sensor fusion and the development of the prognostic engines are not trivial matters. However with the full support of the customer and ONR, these issues while challenging, can be successfully addressed.

PROGRAMMATIC RISK

Programmatic risk is another form of risk that must be managed. The Program Manager will mitigate this risk through sound stewardship of financial resources and customer satisfaction.

An important constituent part of this program is program schedule. Considerable financial resources will have been squandered if technologies are developed after AAAV program insertion points. Extensive effort will be expended to keep the S&T program on schedule and to identify, at the earliest opportunity, any possibility of delay in product delivery.

COMPETITION

Products emerging from this program will necessarily have to compete with other products for space on weapons systems.   Adherence to requirements for performance, form, fit, reliability and cost will be required. The customer will be the sole judge as to the best application to meet his requirement.

OPEN SYSTEMS

Unless there are overwhelming reasons to do otherwise and with due consideration to proprietary rights, all products developed under this program will comply with either de facto or established open systems guidelines.

PROGRAM PLAN

Program Plan TOMS

TOMS Program Activity	**FY02**	**FY03**
Integration and design	⟶	
Design/bench test	→	
Engine test		⟶

Funding Plan TOMS

FY02	FY03
$1.4M	$1.4M

Program Plan AAAV

AAAV Program Activity	FY02	FY03	FY04	FY05
Data gathering, design and assemble hardware for DEMVAL or surrogate, maintenance data management analysis, refine financial metrics	→	→		
Prognostics/reasoning development and integration, refine financial metrics, design for manufacturability analysis	→	→	→	
Field test equipment on AAAV1-AAAV3, refine financial metrics		→	→	→
Redesign as required, support transition to production,				→

Funding Plan AAAV:

FY02	FY03	FY04	FY05
$4M	$6M	$3M	$3M

MARKETING FOR TRANSITION

Ensuring transition of a product from S&T to acquisition is as much about marketing as it is about technology. The Program Manager will be charged with marketing S&T products developed under this program and developing and maintaining a close working relationship with the customer. Additionally, the marketing target of these products shall not be limited to the transition platform, but all products developed under this program will be necessarily designed for insertion into a lead platform.

CUSTOMER COMMITMENT

It is assumed that this program has the full support of the customer. If it becomes apparent that the customer wishes to proceed along a significantly different path, higher authority will be consulted as to program direction and requirement for continued support.

COST CONTROL

Cost control will be a responsibility of the Product Area Manager. He/She will keep the S&T lead informed on all financial issues.

RETURN ON INVESTMENT

QUANTITATIVE

The AAAV MLP effort will transition capabilities and products. These transitions will yield significant ROIs. Examples include:

- 10% reduction in AAAV engine and transmission maintenance hours with an estimated reduction in maintenance man-hours of 50,000 annually
- Reduction in AAAV maintenance manning by ¼ billet/vehicle

QUALITATIVE

Qualitative ROIs include enhanced readiness and visibility of ”fight” (or remaining useful life of monitored systems) left in the AAAV. Other metrics are the reduction in HAZMAT resulting from the TOMS program (on-line vs manual oil sampling) and reduced logistics footprint these technologies will enable.

ACRONYM LIST

Glossary of Terms

AAAV	Advanced Amphibious Assault Vehicle
CBM	Condition Based Maintenance; concept where maintenance is performed only on objective evidence of need
Customer	Government/industry (DRPM AAAV and General Dynamics) team responsible for design, construction and fielding of platform
CY	Calendar Year
DoN	Department of the Navy
DRPM	Direct Reporting Program Manager (AAAV PM)
DUST	Dual Use Science and Technology program
EMD	Engineering, Manufacturing and Design
EVM	Earned Value Management
FNC	Future Naval Capability. A desired future capability articulated by DoN senior leadership
FRP	Full Rate Production; an acquisition milestone
FY	Fiscal Year
GD	General Dynamics, AAAV prime contractor
IEEE	Institute of Electrical and Electronics Engineers
IPT	Integrated Product Team. In this context "IPT" will refer team assembled to execute this program.
LRIP	Low Rate Initial Production; an acquisition milestone
MURI	Multidisciplinary University Research Initiative
NPV	Net Present Value

O&S	Operating and Support Costs
OEM	Original Equipment Manufacturer
ONR	Office of Naval Research
Open Standards	Widely accepted and supported standards set by a recognized standards organization or the commercial marketplace.
Open System	A system that implements sufficient open standards for interfaces and supporting formats to enable properly engineered components to be used across a wide range of systems. An open system is defined by use of accepted or de facto standards and non-proprietary interfaces.
POL	Petroleum, Oil and Lubricants
Product Area Manager	S&T representative having cognizance over the management and execution of a specific subset of a FNC program
ROI	Return on Investment
S&T	Department of the Navy Science and Technology
S&T lead	A senior S&T representative having cognizance over the management and execution of a FNC program
Spike	S&T response to a defined DoN top priority
(TOC) Total Ownership Cost	TOC includes all costs associated with the research, development, procurement, operations, logistics and disposal of an individual weapons system including the supporting infrastructure that plans, manages and executes that weapons system program over its full life. TOC also includes cost of common support items and systems incurred because of the introduction of the weapons system.
TOC IPT	IPT having cognizance over the TOC IPT. Membership consists of Requirements, Acquisition and S&T representatives at the Flag/SES level.
TOMS	Total Oil Monitoring System

Transition	Insertion of S&T product into platform. Product can be hardware, software and or process.

Mission Life Prediction for AAAV

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The issue

Emerging technologies can provide the Operational Commander with situational awareness and intelligence at an individual asset level:

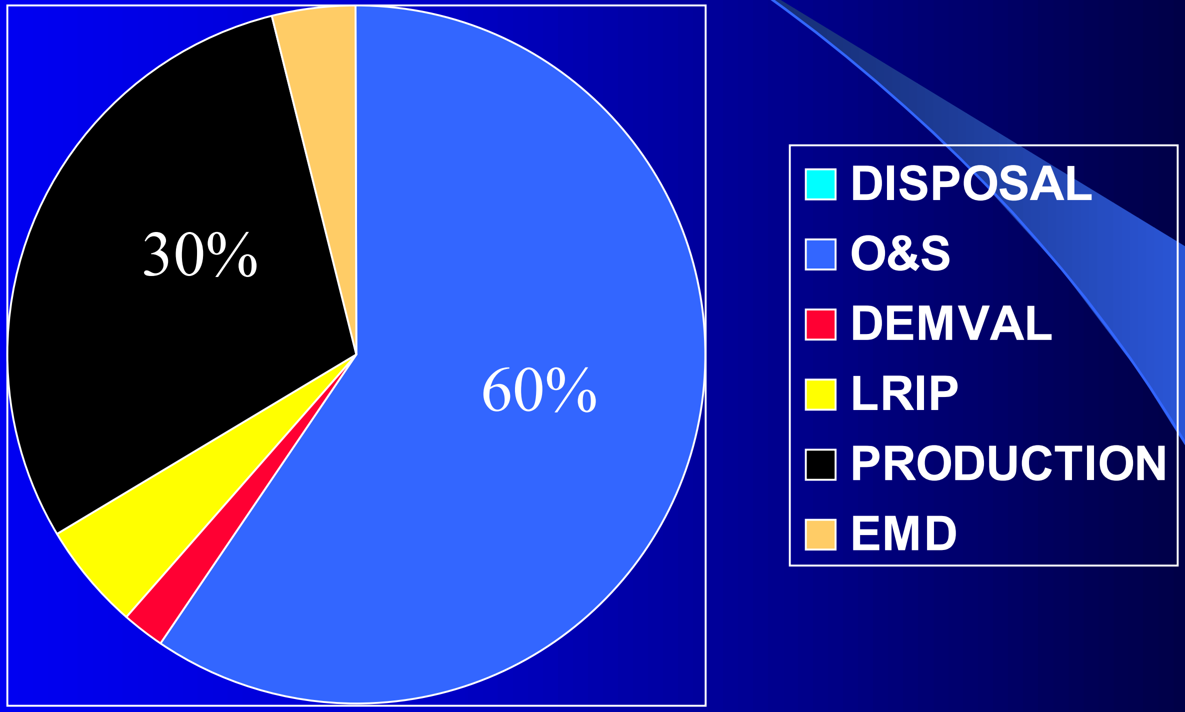
- Platform mission capability
- Pending mission degrading faults
- Confidence in completion of assigned mission

How much fight is left in my weapon system?

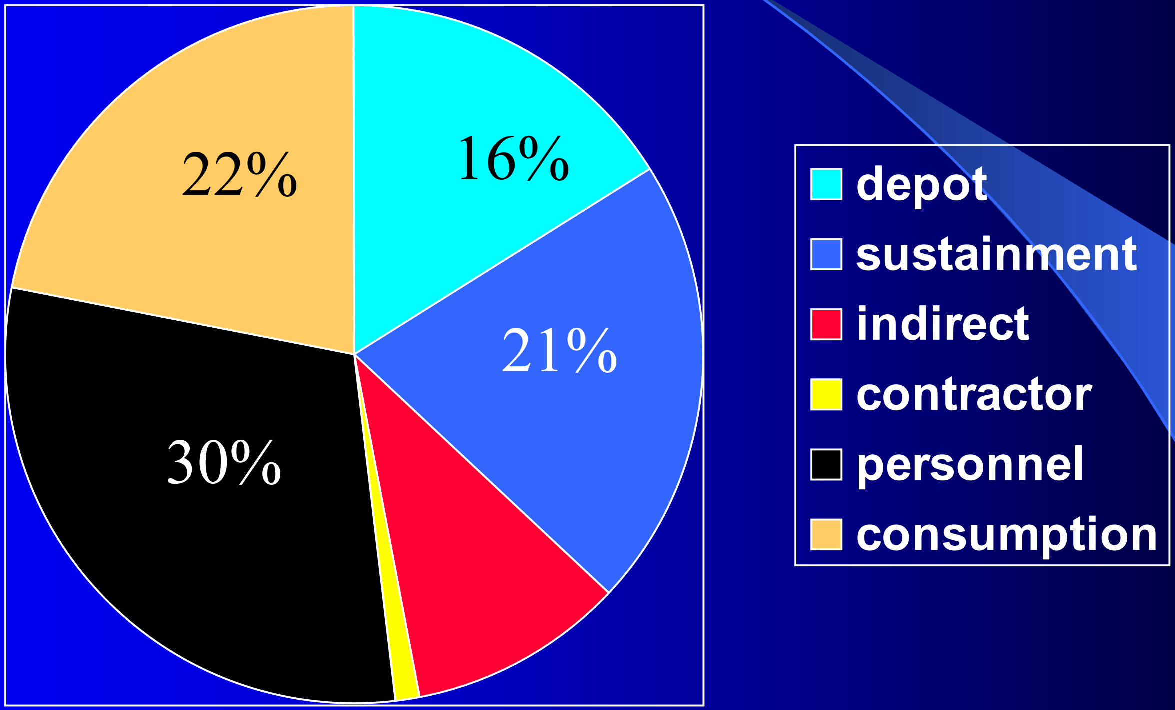
The need:

- Accurate assessment of "fight" left in an individual asset
  - D+P=MLP
  - Enables options for rapid force reconfiguration
- Reduced logistics "footprint"
  - Maintain equipment when it is about to break when optempo permits
- **Significant TOC reductions**
  - **Reduced maintenance manpower and spares with increased A_o**
- Effective Asset Management
  - Real performance, usage and diagnostics data to OEM's, Depots, leaders and managers at all levels

What makes up TOC?

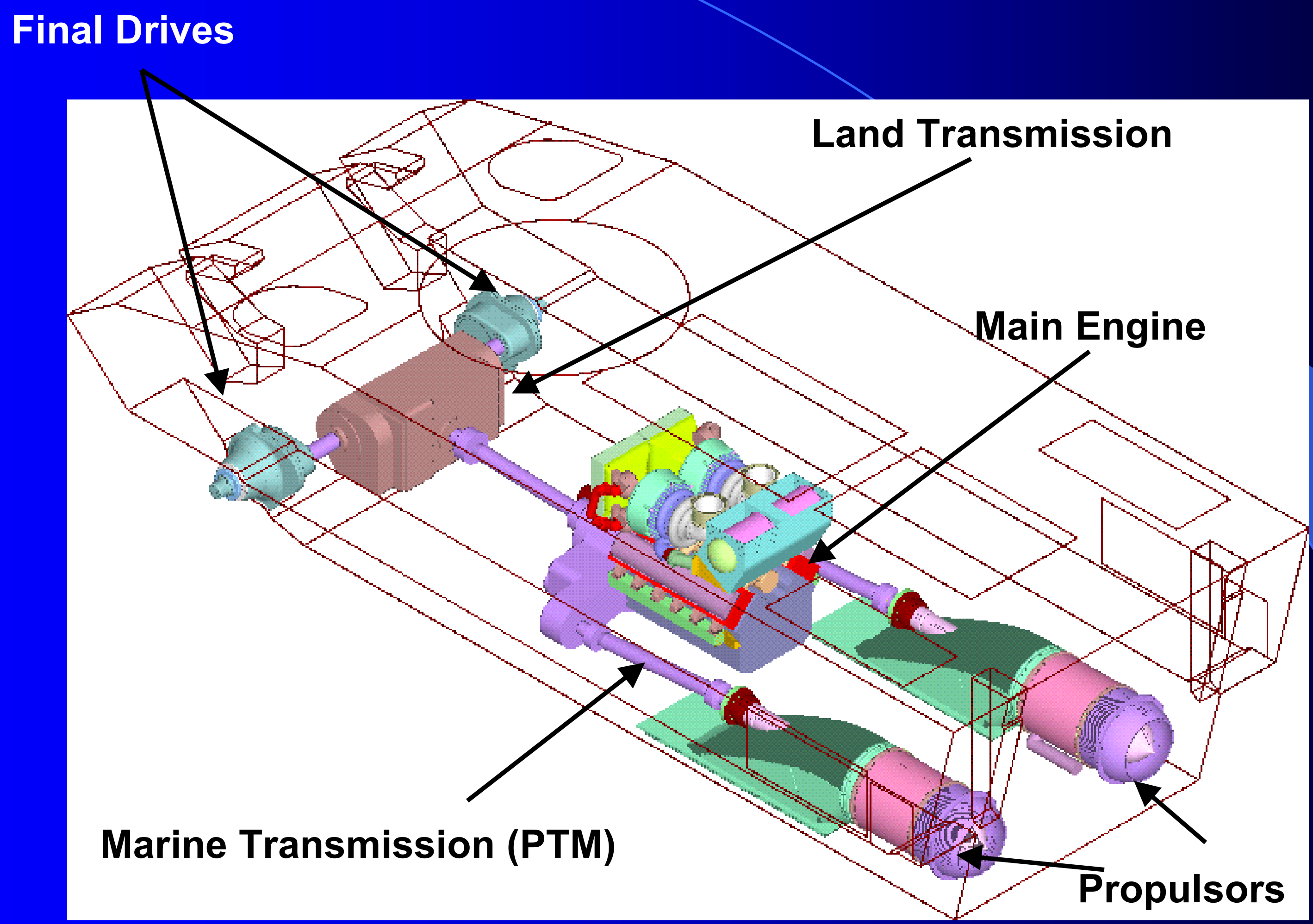


Where do O&S Costs come from??

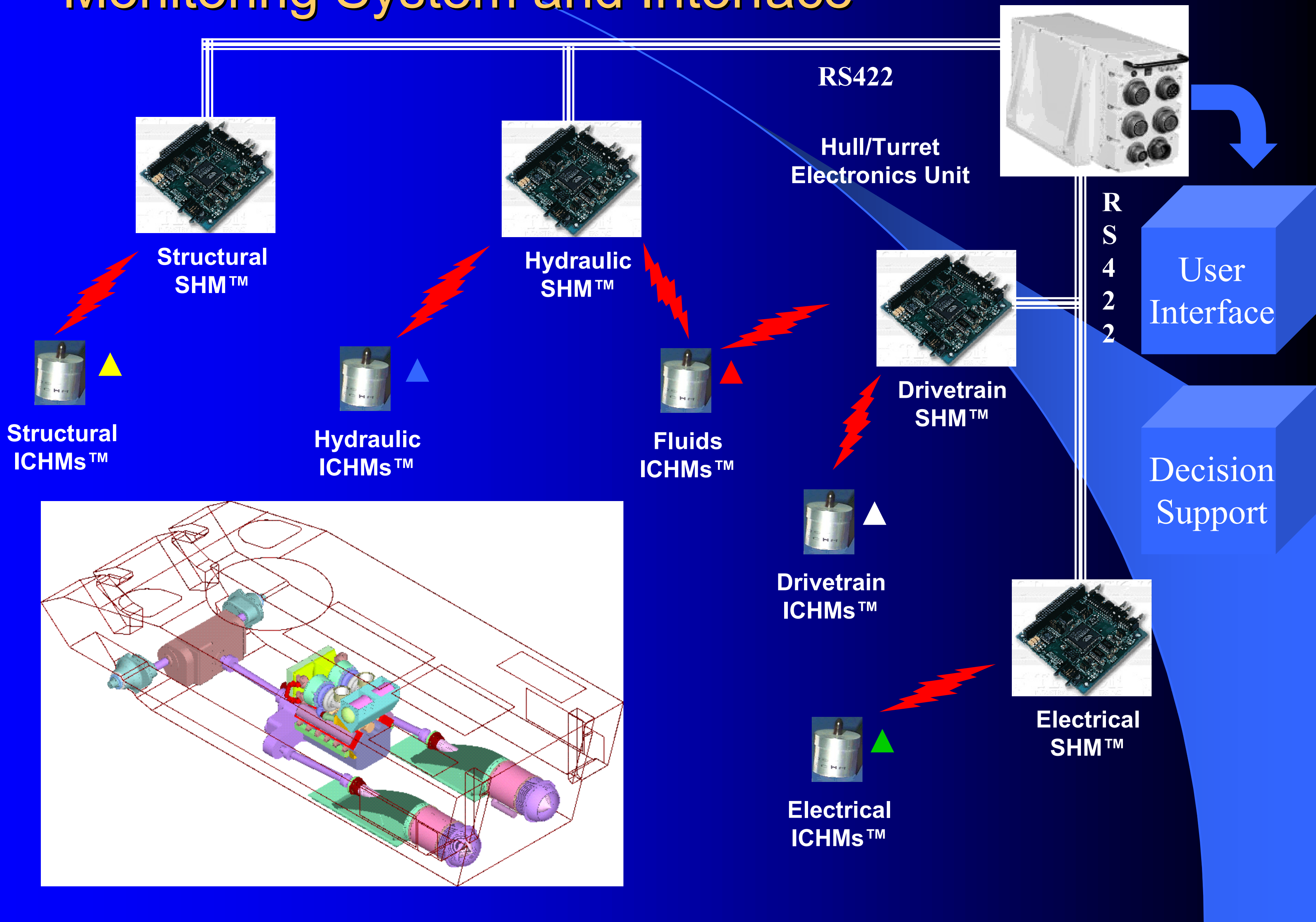


Technologies Include

- Sensors: small, smart, inexpensive, wireless...sensing vibration, temperature, oil/hydraulic system fluid chemistry. WWW-compliant for remote reprogramming, trending etc
- Wireless networks: wires are *the limiting factor* to effective monitoring and diagnostics. Wireless networks will achieve desired characteristics: bandwidth, reliability, power, weight...
- Internet: OSA-CBM provides open Internet-based standards for communications at all levels from the sensor to the decision maker.
- Automated Maintenance Environment (AME): Interfaces with SPAWAR/NAVAIR AME technology environment to integrate Mission Life Prediction (MLP) w/logistics infrastructure
- Decision Support and Capable Manpower FNC products employed in the OSA-CBM architecture provide useful access to new information for theatre commander, technician, and designer.


Final Drives
Land Transmission
Main Engine
Marine Transmission (PTM)
Propulsors

Platform Wireless Distributed Monitoring System and Interface



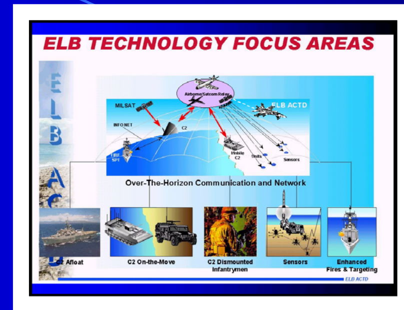
Risks

- Multiple technology integration in platform
- Prediction horizon and certainty in operational environment
- Hardware reliability and cost
- Integration with evolving theatre-wide communications infrastructure

Risk Mitigation

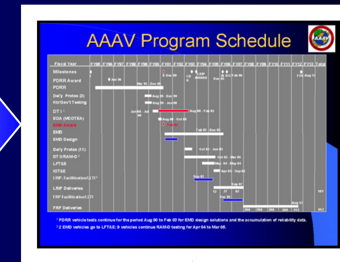
- Five year program in CBM w/ diagnostics and prognostics thrust…supported by two MURIs (PSU and GA Tech)
- DUAP for development of wireless, smart sensor
- DUAP for sensor employment on JSF alternate engine
- STTR for development of AAAV CBM architecture…monitoring of AAAV DEMVAL vehicles starts summer 2000
- DUST for development of OSA (Open Systems Architecture) CBM

Leverage or Other Efforts

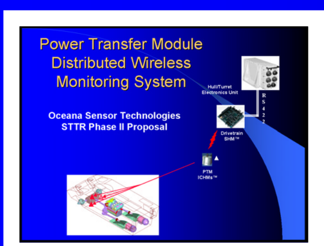


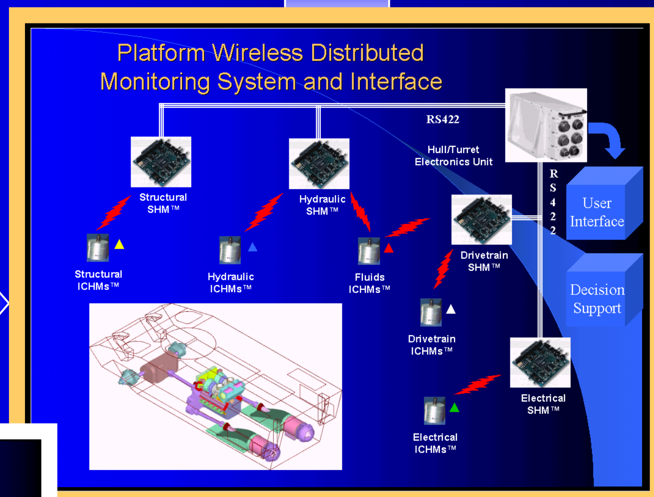
ELB ACTD Program
- C^2 On-the-Move
- AAV Initial Field Demo

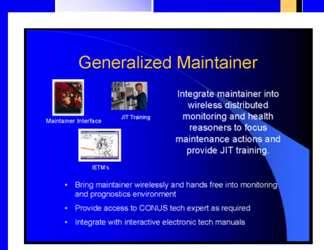
AAAV Program
- 3 Vehicle Dev Test
- LRIP Transition



AAAV STTR Program
- Architecture Demo
- Platform Experience

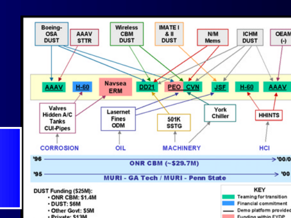






Generalized Maintainer
- Reduce Training
- Situation Awareness

ONR CBM Program
- Initial Concepts
- Prognostics



Benefits

- Open system architecture inherently scalable and transportable across applications
- Wide industrial market to drive cost from underlying technology
- Timely logistics intelligence optimizes support infrastructure

The art of the possible

Conclusion

The opportunity exists to insert current technology in the AAAV….not technology that is current now, in early 2000, but the technology that will be current when the vehicles roll out ….technology that will revolutionize sustainment of combat platforms. This will be achieved by:

*adherence to open standards (OSA CBM)

*non-proprietary solutions (Bluetooth, IEEE, Internet)

*genuine leverage of S&T investments