Business Case Analysis (BCA) with a Modeled Enterprise (BeCAME)

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Abstract

To gain funding to apply Prognostic Health Management (PHM) to an existing program with LRUs “in service”, a Capabilities Based Maintenance Plus (CBM+) decision process was required (by PMS-408 CREW systems). To accomplish CBM+ process, a Business Case Analysis (BCA) was needed to justify the anticipated development and deployment cost for the desired anticipated benefits (Material availability, Ma). The number of deployment and support options directly affect overall costs as well as the wear and tear on the equipment. Therefore a series of models were (are) needed. First, a model of the existing enterprise was needed to compute equipment failure rates and associated repair costs (which affirmed the standard 70% of cost is in the maintenance). Then an interactive statistical model was (is) needed to provide an Analysis of Alternatives (AoA) for the selected set of assumptions (# LRUs, #/mission, #missions, etc). Finally, the assumptions can be adjusted to select Ma as a function of Cost for a given set of assumptions. The results demonstrate the effectiveness of using the Ma assessment to determine whether to re-deploy or refurbish a unit.

Contents:

Introduction

Consider a fleet of similar vehicles where some have been shot at, others exposed to Improvised Explosive Devices (IEDs), and some specially equipped to defeat the detonation of these explosives, Improvised Explosive Devices (IEDs) via Counter Remote Control IED (RCIED) Electronic Warfare (CREW) systems.

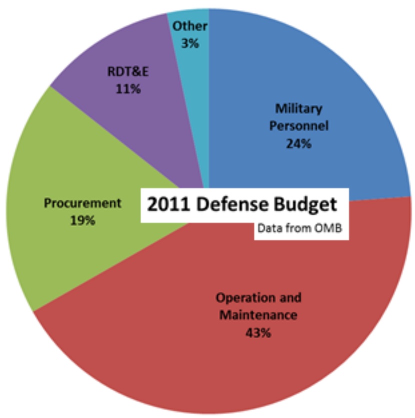
Soldiers protected from Improvised Explosive Devices (IEDs) via Counter Remote Control IED (RCIED) Electronic Warfare (CREW) systems

The soldiers who are protected from these IEDs depend on these aging systems that perform this element of the mission and have suffered from equipment availability problems during rugged use.

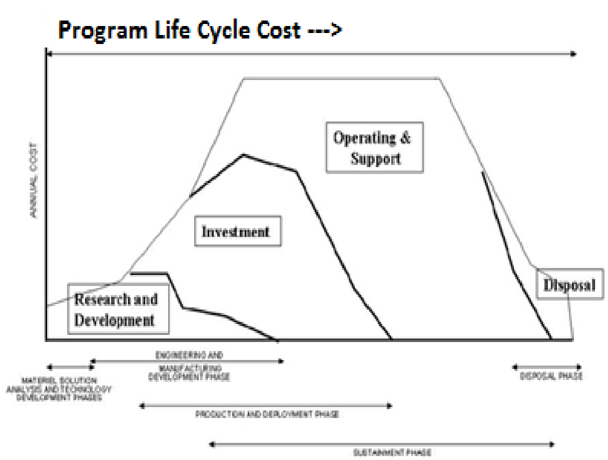
Where Is Defense Money Spent?

Thanks to good equipment to begin with, and world class logistics pipeline, the US military has succeeded in extending the life of many military “systems” while also performing subsystem upgrades and regular maintenance. These operations are even more expensive (usually 2x) than the original purchase of the equipment [8].

As the graphics depict, Operation & Maintenance (O&M) costs are the largest part of both the Defense Department Budget and lifecycle costs within a single program.



Regardless of good service there are things that simply wear out or break after excessive use beyond their intended lifetime, analogous to a very old car that doesn’t reach a total end of life until something fails that’s more valuable than the vehicle (engine or transmission). Meanwhile the same old car keeps on racking up repair costs in the systems that do finally wear out (bearings, ball-joints, wire-chafing, and so-on). These are the “Failure Modes.



Electronic Equipment Failures

Electronic equipment wears out just like moving parts do, but the failure modes are different.

For electronic systems the primary failure modes are mostly related to environmental exposure such as temperature, humidity, and physical shock. The components themselves have a wide range of sensitivities making them sensitive to the environment in ways that may not ever be known during their lifetime, even if they become the highest failure rate components in the systems.

These effects are well known and 2010 led to a Small Business Innovative Research award to Evigia Systems, Inc.

Past Scientific Analysis

Research into prognostics began long ago. In 1976 Dempster Laird and Rubin published a “Maximum Likelihood from Incomplete Data via the EM (Estimation, Maximization) Algorithm” [1]. This made use of Kalman Filtering techniques that were well documented by Robert Grover Brown’s book in 1983, Introduction to Random Signal Analysis and Kalman Filtering [2].

The author, Mr. Reitz, applied the Box-Jenkins and Kalman Filtering techniques described by Brown in his thesis in 1991 on “Fault Prediction With Regression Models,” [3]. At the time, computer resources were limited and fault detection by Built In Test was considered good enough, meaning the application of the technique toward maintenance was ahead of its time (or so the world seemed to think regardless of the 2/3 spending on Operations and Maintenance (O&M)).

In 2003, Murray Huges and Delgado applied Rank Sum feature selection and Support Vector Machines to predict failures of hard disk drives. These techniques are interesting in that neural network clustering techniques are used to identify features that indicate eminent failures while ignoring the failure modes of the constituent devices that can cause them.

In 2007, Leon Lopez continued the application of pattern recognition methods with the application of Bayesian Neural Networks to prognostics [4]. This makes sense in that the Bayesian covariance matrix used to project trends can be better focused on detection of a looming failure rather than running a trend past a threshold as was done by Mr. Reitz in 1991 [3].

Considering these past efforts, the most significant portion of the challenge remains gaining access to the data-flow with the "truth" associated with the leading indicators. In other words, making sense out of the data requires the right data. Intuitively that would include data that has any statistical relevance to failures such as temperature, humidity, and physical shock.

Recent Past Work to Apply PHM

More recently, work by AAC, Evigia, the Navy, and others has resulted in SBIR contracts [4, 5] for Evigia to produce a data logger sensor microsystem that would be used for "Prognostic Health Management" (PHM).

Once the PHM microsystem device requirements were fixed, an Application Specific Integrated Circuit (ASIC) was fabricated and verified.

The Navy became interested in the use of the device for missiles and other explosive systems and began to analyze how to make use of the device. As the problems with missiles were solved, the Navy turned their attention to some electronic warfare equipment that's getting old but is still highly valuable for keeping soldiers alive during combat operations subject to IEDs.

The ASIC Data Logger device is C-MOS and features software that manages its instructions to conserve power so that it can operate over 5 years on a LiON battery cell (eg: CR2032).

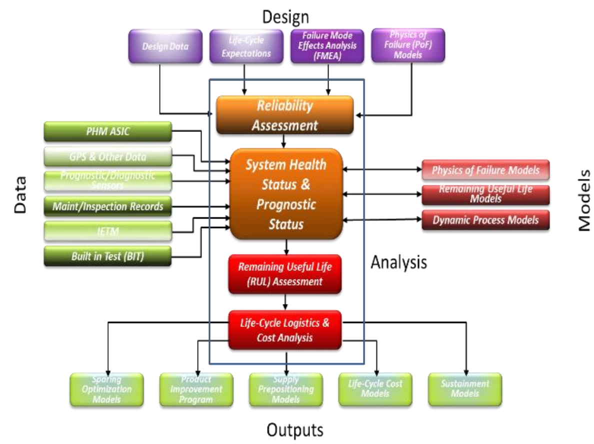
The PHM ASIC logs environmental exposure conditions of equipment over time including temperature, humidity, and shock. The measurements support:

- Forensics – "Why did it fail?"
- Diagnostics – "What's wrong?"
- Prognostics – "Will it still work?"

Prognostics are especially useful to enable preemptive repair that can improve availability at lower cost. For prognostics to work, the forensics must capture environmental events that induce the failure modes of the devices. Then diagnostics (Built In Test) trends as well as exposure conditions can inform the algorithms performing the Remaining Life Estimate (RLE).

Business Case Analysis

The basic PHM Methodology takes that idea as far as possible. It begins with a centralized information system that can track the system health and status as correlated with exposure records. These are invaluable for prognostic Remaining Life Estimates.



System Development Process

In some ways, the analysis work was similar to a Level Of Repair Analysis (LORA), but with additional sensors, the determining factors for the spares and cost elements can shift with the frequency of the maintenance actions.

Objectives

The intent of the BCA was to develop a system model and verify the design would actually provide the cost and performance desired when applied to these aging systems.

During the ASIC fabrication testing, the BCA work began to prove the premise that that the algorithmic analysis of the environmental sensor measurements together with the equipment records really could achieve a cost savings with a simultaneous improvement in Ma when applied to electronic equipment.

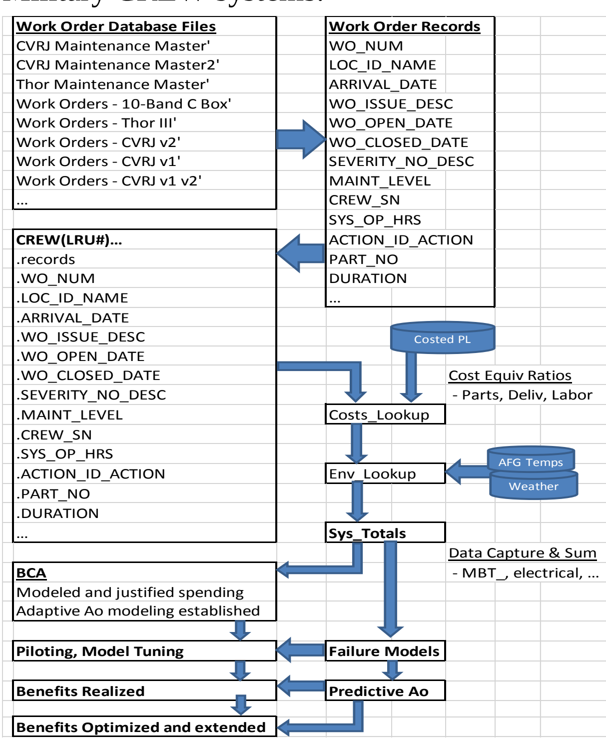
Data Analysis

Asset Management is often faced with conflicting requirements and lacking information. Recent innovations in asset tracking have been named "Total Asset Visibility". These systems track equipment Unique IDentification (UID) numbers with the Asset locations.

Working with aging equipment, the UID and asset location is not enough to have any confidence that the equipment in question is in good enough condition for operational use (Availability (Ma, Ao, or Am)). Elapsed Time Indicators (ETIs) are a step in the direction of "intelligent" asset visibility (knowing what asset is where AND its conditions AND its capabilities).

Work Order Records (WOR) Analysis

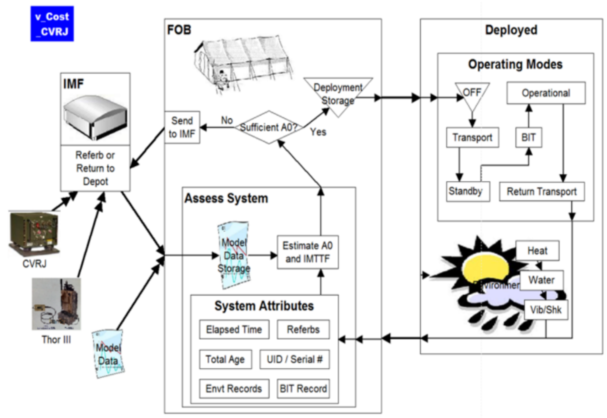
AAC was given work order records for US Military CREW systems.



Analysis of Work Order Records

These were analyzed by spreadsheet, ProcessModel™ software, and ultimately by Matlab™ augmentation of the ProcessModel™ diagrams.

ProcessModel™ is analogous to an activity diagram of the Universal Modelling Language.



Activity Diagram of Deployed Systems

By maximizing the real data import features of the tool, early results revealed impressive observations. One such observation was how the Afghanistan "surge" affected the number of WORs.

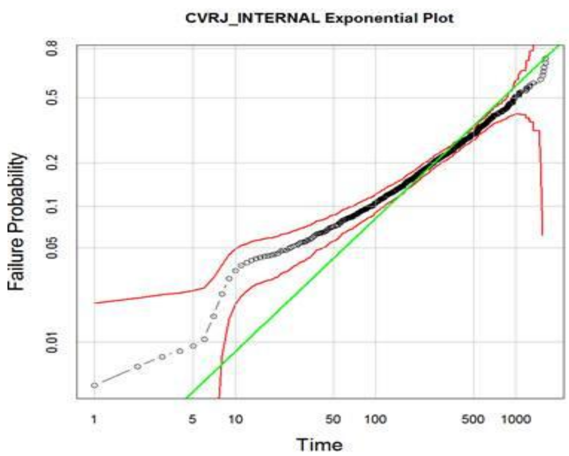
Implications of the Data

With the intent of associating exposure conditions to the WORs, weather station data was obtained and Matlab™ was used to make correlations. This followed a similar observation made previously by others who were examining the same data. That is, the equipment seemed to fail more often during spring and fall than winter and summer.

Additional analysis by others provided more detailed failure distributions. They observed:

- External components are close to exponential – random failures;
- Cable has slightly different model with significant low time failures;
- Internal components have decreasing failure rate with age – infant mortality.

AAC analyzed these failures together with others to obtain the failure rate parameters for these components (MTBF and Weibull "K").

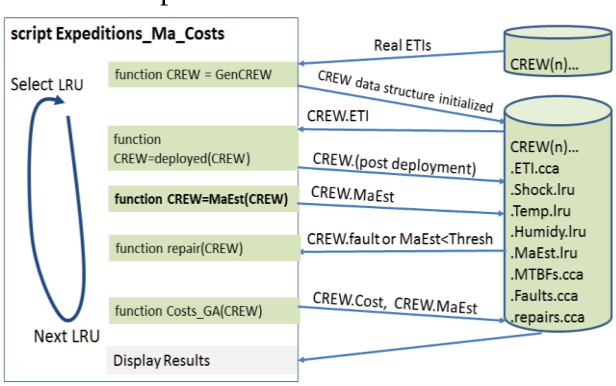


Failure Distributions Over Time

Use Case Models

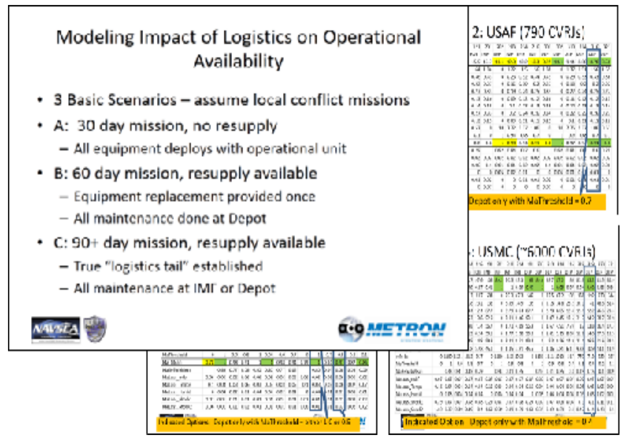
Use Case Models can be used to plan the PMS 408 sustainment needs for spares, availability, and cost to support the total number of CVRJ devices used by a specific group for a specific time. It also addresses the mission-specific sustainment needs for mission planning.

Using Elapsed Time Indicator (ETI) and failure data in a new Matlab™ model, the costs and equipment availability were simulated. A selectable Ma threshold estimate was used to initiate preemptive repair. It then used a strawman model of how the statistical environmental conditions affect the equipment life, the "failure modes". This model also produces the "Remaining Life Estimate") needed for operational use.



Analysis of Use Case Scenarios

Using this model, a set of "use cases" were simulated. The model used an array of ETI recordings that represent actual equipment and statistically processed the fleet of equipment according to the failure mode models and mission/Use Case parameters.



Use Case Analysis Results

The "use cases" related directly to how the equipment is to be used by groups within the US Military over the next 5 years.

Option/Description	Cost *	Ma **	Comments
1. Repairs at FOB IMF, DEP	145	0.38	Current State
2. DEP only Refurbs for .99	122	0.99	no FOB repairs
3. FOB Repairs + DEP Refurbs	133	0.99	no FOB repairs
4. Repairs at IMF, DEP	125	0.38	close to DEP only
5. IMF only Refurbs for .9	128	0.9	close to DEP only
6. Depot Only Refurb for .99	113	0.99	Best Ma for $
7. Depot Only Refurb for .9	86.4	0.9	Best $ for Ma > .9

Example Use Case Optimization

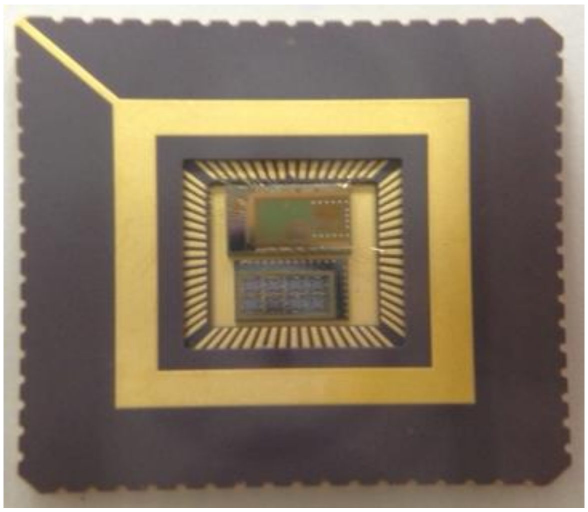
In all of the use cases analyzed, preemptive repair of the high failure rate boards both increased Ma (can save lives) while reducing the total cost.

Implementation Directions

To achieve the benefits the BCA demonstrates, AAC and Evigia are continuing to work with PMS-408 to pilot several elements of the positive results. These include a data-logger, Mobile/Web applications, piloting of 1000 data-logger devices with mobile readers, and adjacent new programs.

Data Logger

The Data Logger is designed to capture changes to environmental conditions over the life of a product. Evigia has produced the PHM Data Logger ASIC in low volume for device testing and is now gearing up for LRIP and production.



Prognostic Health Management ASIC

The ASIC is mounted together with a battery on a circuit board and a mini-USB connector into a hermetically-sealed package for external installation onto the product of interest (CREW systems in this case).

The mounting location of the Data Logger onto the equipment is a compromise between the validity of the logged readings, and not disturbing the operation of the equipment. Internal heat sources, external physical contact, attachment, and other factors must be considered.

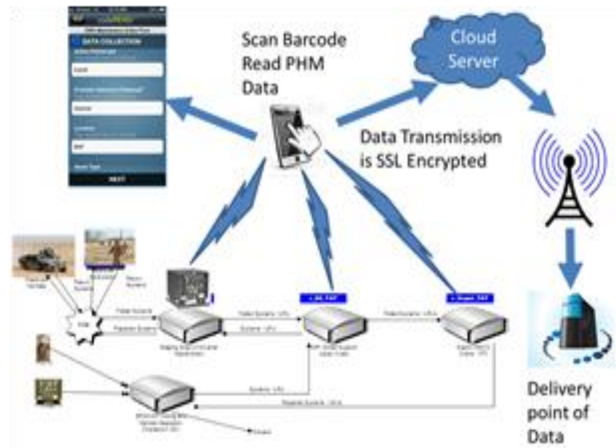
Data Logger

For the CVRJ, the selected mounting location is on the bottom cover between the Line Replaceable Unit's shock-mounts (feet).

AAC has scheduled the purchase and deployment of 1000 of these devices to be applied to CREW systems that are actually deployed.

Mobile/Web Applications

AAC has developed a web-based database application conceptually derived from the automotive transport business (VinDelivery™).



Web and Mobile Applications

The mobile application features barcode scanning of the UIDs, data entry of the ETI, menu selected text, photos, videos, GPS location, and Workflow Automation Management (WAM).

Once the data is collected, the analysis can be more effective by using real data-records rather than simulated estimates.

In addition to the FRACAS/COLTS database system, the system also features its own data server to warehouse the added prognostic related data such as the environmental exposure conditions.

Testing will validate that **electronic equipment availability can be improved while costs are reduced**. To this same verification and validation criteria, the BCA preceded the field trials development phase with the same objective.

Conclusions

The modelling and simulation have demonstrated use cases that suggest a 60% reduction in Life Cycle Cost achieved by preemptive repair whenever an LRU's remaining life estimate falls below a desired threshold.

According to use case scenarios of the model, even low thresholds for preemptive repair appear to save money while significantly improving Material Availability (Ma).

Evigia has developed the first prototype data-logger devices, and a simulation of the web-application is already being tested with real systems in deployed locations such as Afghanistan.

As the equipment data re-enforces the system modelling, the PHM technology will become more effective in reducing total cost. To this end, AAC intends to use this device as it becomes possible to apply it to adjacent programs. The fact that the data logger is built with a micro-controller (8051 core) makes it useful for embedded applications.

These future products include very large HD displays, PowerPacks for electric vehicles, surgical robotic equipment, and an array of microprocessor applications that benefit from the environmental recordings.

AAC expects that the nature of these results together with the low cost of the data logger device will lead toward a more intelligent use of assets based upon the assets themselves.

In the past **Total Asset Visibility** was considered to be a great advance over material inventories. Yet now, Prognostic Health Management (PHM) has become possible. This enables a new level of asset management that includes the operational Availability (health status) of the equipment. In this way, TAV is transformed into **"Intelligent Asset Visibility"**!

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