Repeating Design Errors or “Where’s The History?”

Randal D. Bennett
University of Maryland University College
805 Montview Dr
Escondido CA 92025

Crystal D. Sloan
EagleRidge Technologies, Inc.
114 Ledgerwood Lane
Rockwood, TN 37854
onetahiti@alum.mit.edu

Abstract. The Oliver Hazard Perry class of frigates and the Arleigh Burke class of destroyers, the US Navy’s newest combatants, share a common design fault despite, or perhaps because of, a 20-year difference in design time. This paper describes the fault and links the underlying cause of the error to a lack of readily available historical knowledge. A solution is proposed to prevent the recurrence of error repetition by increasing the visibility of corrective maintenance actions to designers and of the status of material condition throughout the fleet to the maintenance managers and operations planners. The results of the process include better design, elimination of repetitive design errors, and true depictions of fleet readiness as a systems engineering solution.

INTRODUCTION

The (Oxford English Dictionary) defines “error” as “a mistake in the making of a thing.” A “blunder” is therein defined as “a gross mistake” and (Merriam-Webster) further qualifies a blunder as “a gross error or mistake resulting usually from … ignorance ….” These two words are accurate representations of design decisions with respect to the control systems used in the engineering plants of two classes of US Navy warships.

The Oliver Hazard Perry class of guided missile frigates uses an Engineering Control System to start, monitor, and stop main propulsion and electrical power generation equipment and to monitor and provide rudimentary control for other systems. The control system is composed of software, two processors, and an extensive cabling system for sensor input and control signal output. The monitoring and control subsystems for most of the equipment share a common, ungrounded bus.

The Arleigh Burke class guided missile destroyers were introduced in the early 1990s as more capable replacements for the aging Spruance class destroyers. Once again, an extensively automated remote operating and monitoring capability, called the Machinery Control System, was included to sustain reduced manning requirements in the engineering spaces. The Machinery Control System of the Arleigh Burke destroyers has many architectural commonalities with the Engineering Control System of the Oliver Hazard Perry frigates.

The US Navy collects data on corrective maintenance through the Maintenance Data Collection System. Reports of corrective maintenance are tied to ship configuration files, and orders for replacement parts are tied to the maintenance actions. Configuration Data Managers, located at geographically dispersed locations throughout the United States and usually at Naval or private shipyards, manage the configuration files, which are updated by modernization maintenance action reports. Even though the Maintenance Data Collection System is more sophisticated now than at its inception, there are inherent shortfalls that trace their lineage to the limitations of the mainframes and software of the 1960s. As a result of this “dead hand of history," the data collected is nearly useless for analysis because of its resistance to data mining.

All of these characteristics have combined to produce a repetition in design error between two ship classes widely separated by time, technological advances, and functionality.

The Error – FFG-7 Class Engineering Control System

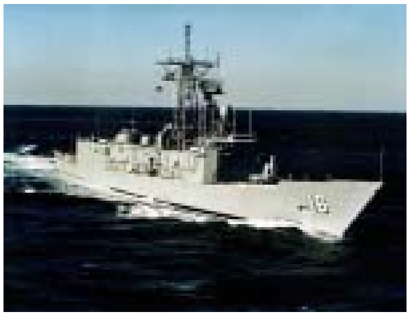

Figure 1. USS Clifton Sprague (FFG 16), an Oliver Hazard Perry-class frigate

The U.S. Navy built the Oliver Hazard Perry (FFG 7) class of guided missile frigates to fulfill several goals. They were badly needed replacements for the aging Knox-class frigates (built in the latter part of the 1950s and early 1960s). They achieved better power-to-weight ratios than their steam propelled counterparts by adopting gas turbine propulsion, first introduced in the Spruance class destroyers. They also afforded a lower acquisition and operating cost alternative to the Spruance destroyers to fulfill the requirements for ocean escorts operating in low- to medium-threat anti-submarine warfare environments (Federation of American Scientists 2002).

While much of the cost avoidance in operations can be traced to the difference in the size of the two classes of ship, significant savings are achieved by adopting an austere-manning concept that relies on what was at design time a highly automated Engineering Control System (ECS). The ECS provides remote start, monitoring, and stop capabilities for the power generation and distribution and main propulsion systems, and limited monitoring and control for auxiliary and damage control systems. The control system employs application specific software, two processors, and an extensive cabling system for sensors and control that uses shielded cables with wire-braid sheathing. The monitoring systems for three of the four subsystems, main propulsion, power, and auxiliary share a common ungrounded bus, and the damage control subsystem has its own bus.

The cable shielding is the control system's Achilles' heel, being susceptible to failure with subsequent grounding of the interconnected subsystems. Of the seven causes of system failure described by (Talbot 1993), two are applicable to the ECS: "Design Focus on Nominal Operational Behavior to the Neglect of Start-Up, Shut-Down, Boundary Conditions and/or Error Recovery" and "Design Requirements did not Accurately Reflect Usage."

Boundary conditions are prevalent due to the low voltages within the control system and the narrow difference between the binary conditions of set and unset for alarm or control signals. The grounding of one cable causes a sudden change in the reference voltage that can trigger a signal whose activation point is set close to one side of the adjustment band. This results in one or more phenomena that (Moorhouse 2001) identifies as an "uncontained part fault," a fault with which the system is not designed to cope. In the ECS, the unpleasant side effects in the system range from spurious alarms on the associated equipment, to uncontrolled rotation of an idle propulsion turbine, to "unalarmed stops," a euphemism for an unplanned and uncontrolled shutdown of the operating turbine with a subsequent loss of propulsion.

The ground also leaves the shielding useless, and the system is then plagued with voltage spikes that lead to further control system anomalies. The voltage fluctuations are induced by radio frequency broadcasts from such disparate sources as low-wattage hand-held transceivers used for communications between system operators, and proximal fire control system radars.

Although a number of different approaches have been taken to solve the problem, the one that works, at least in terms of maintaining equipment control, is to install a back fit that provides a ground for the control system, eliminating the spurious alarm and control signal effects of a grounded cable shield.

(Talbot 1993) includes collocation of redundant elements in the "Focus on Nominal Operational Behavior" category, a situation that includes the data bus arrangement on the Perry class frigates. Sharing the data bus among the Propulsion Control Console, the Auxiliary Control Console, and the Electric Plant Control Console was envisaged as a redundancy, but this arrangement has the unplanned consequence of further compounding the problem with cable shielding grounds. The shared data bus ensures that monitoring signals are recorded hourly on the system's data logger and that alarm signals are documented as they occur, regardless of the source of alarm. Unfortunately, it also means a ground in any one of the three monitoring systems can affect signals in any of the three subsystems. Thus, maintenance personnel cannot assume the source of the anomalies is the cable associated with the faulting monitoring or control circuit, and fault isolation requires splitting the data buses as a first step.

Like many other solid-state devices, the processors in both the Propulsion Control Console and the Electric Plant Control Console are intolerant of elevated temperatures. Located as they are within the air conditioned Central Control Station, this would not appear to be a problem until one considers the operating environments faced by the average ship. Deployments, especially those of ships based on the Pacific Coast, routinely involve a great deal of time in tropical waters and, since 1979, in the Arabian Gulf. The shipboard air conditioning plants are taxed to their limits under "normal" operating conditions during these deployments primarily due to the difference between design temperatures and the actual temperatures in these regions. In light of the redundant air conditioning plant installations, the reliance on air conditioning might seem a trivial consideration, and so it would be in a cruise ship. Warships, on the other hand, are subject to hostile fire as well as ordinary equipment failure, and the loss of air conditioning for the heat-sensitive processors implies a rapid, if not immediate, loss of function in a wartime situation, a result (Talbot 1993) describes within the category of "Design Requirements did not Accurately Reflect Usage."

"Design Requirements did not Accurately Reflect Usage" is applicable in another sense, as well. (Talbot 1993) specifically describes one aspect of this cause as "failure to anticipate system deterioration over time, especially with inadequate maintenance and upkeep." Most of the grounds in the control and monitoring cables are not attributable to abuse or misuse. Rather, they arise from continuous exposure to vibration associated with sustained ship operations, i.e., normal wear and tear. The low operating costs make the Perry frigates attractive to both the regular and reserve Navy, and their size, both physical and crew, make them especially attractive to the Naval Reserve Forces. Because of this attraction, and because there is no other ship in the inventory that offers the flexibility and economy inherent in this vessel, the Perry frigates have endured a life extension without programmatic support. As a result, the problems described thus far are aggravated by retention of a low-cost vessel well beyond the design lifetime, and they are further exacerbated by insufficient allocation of maintenance funds fleet wide during past administrations.

The Blunder – DDG-51 Machinery Control System

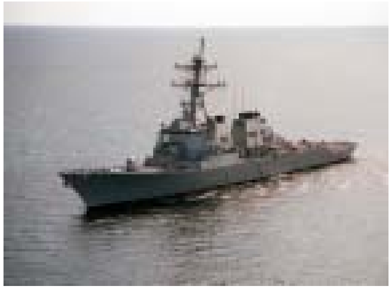

Figure 2. USS Cole (DDG 67), an Areligh Burke-class destroyer

The Arleigh Burke (DDG 51) class guided missile destroyers were introduced in the early 1990s as more capable replacements for the aging, high maintenance Spruance-class destroyers (Federation of American Scientists 2002). The ships were designed at the Bath Iron Works in Bath, Maine (Naval Vessel Register 2002), a yard famous for the quality of its products. (A "Bath-built ship" holds a near-legendary status among the U.S. Navy's engineering personnel, testimonial to this builder's commitment to quality that quite literally spans decades.) Like the Spruance destroyers, they are a "high mix" system, employing more costly and more capable systems than the Perry frigates.

Like all the gas turbine powered predecessors, the Burke destroyers employ an extensively automated remote operating and monitoring capability for the engineering plant, the Machinery Control System, to sustain reduced manning requirements in the engineering spaces. The system includes technological improvements achieved over the intervening decades in terms of processor speed, power, and bus architecture. The monitoring and control wiring harness of the Machinery Control System is composed of shielded cable with wire-braid sheathing, similar to that of the Perry-class frigates, and equally susceptible to damage from vibration alone. The processors are reliant on air conditioning, and there are data buses shared between the operating consoles.

Within ten years of their introduction, the Burke-class destroyers are beginning to exhibit the same control system anomalies as the Perry-class frigates. This leads to an obvious question: With 20 years of experience in control system problems arising from the relatively fragile cable shielding used in the Perry frigates, why did Bath Iron Works adopt, and the U.S. Navy approve, a design making use of similar cable for a similar application in a similar operating environment? Further, why did they maintain the linkages between consoles from the Perry design that so vexes maintenance technicians and operators? Finally, why are the processors still so dependent on air conditioning?

Cause of Error Repetition

Accessible History. One of the more famous quotations of (Santayana 1905) applies here: "Those who cannot remember the past are condemned to repeat it." In the face of ever more complex systems, remembering last year's design decisions is challenge enough in many organizations. The US Navy, on the other hand, is extremely thorough in recording information for historical purposes. For example, each and every ship is required to submit annually a ship's history delineating the command's activities, and this focus on historical information extends to the maintenance world. Given this predilection to recording information, why are any ship design errors, and the control system cabling is only one of many, repetitive in nature? (Degregorio 1999) addresses this particular aspect of information and decision making:

> "The 'information' used to support these decisions is often in the form of complex, unstructured documents which lack clear linkages between their content. As a result, future decision-makers are often not able to benefit from the collective experiences of their predecessors. Consequently, there are no cycles of learning and the same mistakes are often repeated each time that a similar decision is made."

The reason there is no learning cycle is a lack of *accessible* history.

Maintenance Data Collection System. The US Navy uses the Maintenance Data Collection System (MDCS) to record corrective maintenance actions. The roots of this system are traceable at least as far back as the 1960s, and the designs of the data architecture and data collection tools, the OPNAV Forms 4790/2K and 4790/CK, reflect the limitations of the mainframe computers and software in use at the time. This continues despite the modernization of the central data repository and the introduction of shipboard computers of some sophistication to support the data collection. Although gas turbines and their associated controls, as well as some other equipment, have had some tailoring of information collection, the majority of the details of the maintenance actions, including the tailored equipment, is collected within a large text block that does not lend itself to data mining. In other words, the history, although voluminous, is nearly as digitally inaccessible as if it were stored on stone tablets or paper copies. The resistance to data mining translates directly into a huge analysis burden for anyone trying to research previous design failures, a situation which may have contributed significantly to the repetition of design error from the Perry frigates to the Burke destroyers.

Hierarchical Structure Code. The data architecture of the system is arranged by the Configuration Data Managers, the keepers of the "ship configuration files," which are a listing of equipment and components installed aboard each ship. The basic organization of the configuration file centers on the Hierarchical Structure Code (HSC), a 12-character code generated from composite sources (Naval Sea Systems Command 2002a).

The reference describes the function of the HSC as identifying a functional/hierarchical relationship of the ship, ship system, and equipment. As such, it should be the feature that imposes discipline on the data architecture, and its design certainly supports this application. Unfortunately, this proves not to be the case.

The first five characters of the HSC are digits originating in a work breakdown structure developed in the 1950s that could stand modernization, although it has served remarkably well to date. The remaining characters provide a more detailed breakdown of the configuration that can take one of three alignments, and an alignment that is a composite of the other "standard" alignments has also been observed. As a result, the same equipment installed on two different ships of the same class may appear in different locations in the configuration file structure, and the same equipment (e.g., a propulsion gas turbine engine) will almost certainly have different identifiers between classes. In addition, the reference requires the HSC to be unique within the ship database. This also has proven not to be the case, with the result that two or more components are identified by the same HSC, relegating the HSC from primary index to simple data field and contributing to the analysis burden.

Naming Conventions. If the technician attempts to identify the equipment by name, he or she faces another problem in the data architecture: inconsistent naming practices. A single subsystem or component may have its name presented in a number of different ways, most of which are abbreviations of one form or another in order to comply with the data element length strictures. For example, a waste heat boiler may be identified as "Waste Heat Boiler," "Waste Heat Blr," "Wst Ht Blr," "WHBlr," or "WHB," to name some of the permutations. Similar difficulties are encountered with transformers (which may also be identified as "reactors") and circuit cards ("circuit card assembly" and "CCA," to name only two of the possibilities).

Data Disorganization. The amorphous data organization is in direct opposition to one of the "two critical elements needed to provide the foundation for dramatic process improvements: …

an information architecture with internal structures, optimized by domain" identified by (Degregorio 1999).

The lack of organization is a significant contributor to maintenance technician confusion in selecting the appropriate "account" against which to "charge" the maintenance action. Further muddying the waters is the logistic nature of the architecture that provides a parent parts list showing subordinate components, each of which may also have a parts list. This parent-child relationship is sometimes three or four levels deep, but MDCS allows recording a maintenance action against the highest level when it was performed at a level one or more removed from the parent. Some of this is a training issue but has as much or more to do with the time constraints under which the maintenance technician operates. The technician is limited in the amount of administrative time available for recording the information and, if unfamiliar with the data architecture, may give up on searching for the actual equipment "account" and select one of the higher level, or even the incorrect, parent equipment to "charge" the maintenance action against. In the worst case, the technician may give up in frustration and engage in "poke and hope," charging the maintenance action against a generic parts list. As a result, there is no guarantee someone looking for information about maintenance actions on particular equipment will see all of the actions taken. This further compounds the analysis overload.

Data Collection Tools. MDCS uses the OPNAV Form 4790/2K to collect data associated with corrective maintenance actions (Office of the Chief of Naval Operations 1994). The form consists of header information, a text block, and footer information. The header information contains discrete fields for nomenclature and HSC identification of the equipment affected, both already discussed; single digit fields to describe when the fault occurred, how the fault was discovered, the cause of the fault, and which level of maintenance (organizational, intermediate, or depot) should be responsible for repair; equipment operating hours; and information of an administrative nature for use by maintenance managers.

Other than these, however, a single field is provided for recording information concerning indications, diagnostic results, repair efforts attempted, and a recommended solution. Because the field cannot be restricted in data type to accommodate this wide range of information, the operator is free to use any and all terminology, spelling conventions (or unconventional spelling, for that matter), or phraseology. Certain authorities have mandated the use of special codes within the field as well. As a result, this block can hold an extensive amount of pertinent information, but does so in a manner resistant to data mining. Similar problems exist in the tool used to capture configuration change data, OPNAV Form 4790/CK. (Chesterman and Garrett 2001) address this:

> "The documentation of material condition with the OPNAV 4790/2K form is inconsistent. When there are configuration changes, the use of the OPNAV 4790/CK form also is not consistent. Although MDCS has a large warehouse of data the OPNAV 4790/2K is not structured to capture material condition history (objective evidence at the system or component level), making it difficult to mine for assessment or analysis."

Treating the Symptom. The incoherence of the data in MDCS results in analysis overload which has led to the creation of other systems for feedback to provide timely information to maintenance planners and mangers, operations planners, and, to a lesser extent, designers. The Casualty Reporting System is used to help operations planners compute an index of a ship's readiness for operations. It also provides the maintenance planners and designers a rough analysis of the frequency of failure for some systems of interest and a view, however clouded, of the material condition of the ship. Another application provides analyses of parts usage to identify high failure rates among replacement parts, but does not address issues at the system or equipment level and is employed primarily as a quality assurance tool with respect to parts suppliers. Combat systems, those (primarily electronic) systems associated with command and control functions and with delivering ordnance on target, are the subject of the Troubled Systems Program (TSP) that feeds into a high management level process called Top Management Attention/Top Management Issues (TMA/TMI).

These systems are purported to provide the analysis envisaged for the MDCS, but give short shrift to analysis. The parts usage application does not provide a strict analysis of the cause of failure, only a statistical analysis of the number of parts ordered and, as previously stated, is blind at the system or equipment level. The other two programs are also weak on analysis since a candidate equipment is introduced into TSP based on the results of a single inspection type (Naval Sea Systems Command 2002b) as amplified by anecdotal information from technicians, and both were designed from the outset to be reactive, versus proactive, stopgaps for failures of the primary system, MDCS, to provide the action necessary. Further, TSP is applicable only to Combat Systems and a limited amount of other equipment that directly supports their operation, thereby omitting approximately 60 percent of the equipment in a typical ship configuration file. Unfortunately, reliance on these systems to provide corrective maintenance solutions is extremely heavy, and the data analysis is stove-piped, without visibility to other stakeholders.

The Solutions

Two solutions present themselves, one providing both immediate utility and avoiding the exorbitant expense of rearchitecting large data structures as described by (Sloan 2001), and the second imposing future data discipline as described by (Degregorio 1999). In the near-term, recent search engine technology developments provide the means for mining the amorphous data. For the long-term, (Chesterman and Garrett 2001) describe in general the means to achieve the data structure to support rapid cycle time improvement in operations.

Solution 1 - Search Engine Technology. Commercially available search engine services can meet the immediate needs of the designers wishing to mine the data store in MDCS. (Google, 2003) describes a search appliance that is readily available and has been proven adaptable to searching data stores in a variety of different applications.

Initial setup requires authoring a single dynamic web page showing at least one record from the database and containing a link to the next record. The Google search engine is then directed to crawl the database using the single dynamic web page with successive records being tasked.

Once the database has been crawled, users can then access the data from a web page using a familiar search box. The crawling and accessing preserves security of the site, so that users can see only authorized results.

Hence, with one dynamic web page, the full power of a search engine correlation on the free text in the legacy data can be used. Further enhancements can be made using search engine positioning techniques involving the generation of appropriate keywords and HTML META tags in the displayed web page as users gain experience with the system.

With several terabytes of database to crawl, the spider's initial pass through the database will be time consuming, but, since the data is relatively static, subsequent crawls can be directed to new or changed records using additional dynamic pages.

In addition to the inherent search capabilities of leading engines, system administrators can establish a dictionary of equivalencies as keywords in the dynamic web page. This will reduce the confusion associated with variant terms by relating standard terminology like "waste heat boiler" to other abbreviations such as "wst ht blr," and "whb."

Thus, in the short run, search engine technology, implemented as described, can speed the discovery of recurring issues experienced with in-service systems in order to prevent blundering, or at least mitigate the causes of the difficulties in the next design iteration. The search engine solution described here is attractive because of user familiarity with the technique and the low cost of implementation. However, the answer to Degregorio's architecture requirements (Degregorio 1999) for rapid cycle time improvements in operations is given by (Chesterman and Garret 2001).

Solution 2 - Data Architecture Discipline. The first step in the data architecture solution is to impose discipline on the data architecture. A single standard for organizing the configuration file is necessary to ensure the data collected is associated with the correct equipment. (Degregorio 1999) states, "Rapid cycle time improvements *cannot* [emphasis his] be achieved without an underlying information architecture …"

For the configuration files, this entails realignment so the same piece of equipment in the same application carries the same HSC identifier, the same nomenclature is used for identical and equivalent pieces of equipment, and the standard alignment carries over from class to class as well as from ship to ship. The following examples are provided for clarification.

A system or equipment should always be found in the same place within the hierarchy on every ship within a class. A valve should be called "valve," "vlv," or "v," but not all of these. A propulsion gas turbine engine or Close In Weapons System (referred to as "CIWS" or "Phalanx") fulfils the same functions and has essentially the same architecture no matter the class of ship, so it should always carry the same HSC structure in every class.

The realignment will also require an expansion of the HSC structure to provide a code for every component on board. As an example, the barbette of the CIWS is missing from the hierarchical structure on at least one ship class yet is the source of some failures of the system.

The realignment will help to ensure data collected is linked to the correct equipment, easing both the reporting and the analysis burdens. It will ensure that problems with a particular piece of equipment, such as the gas turbine control system, receive visibility, regardless of the source in terms of ship class, so that control system problems in one class are not overlooked when designing a ship of a different class. Further, it will reduce labor costs for the Configuration Data Managers at new construction since the entire hierarchy of a system, subsystem or component can be imported from an existing structure. Finally, it provides the foundation for the centralized data warehouse that (Chesterman and Garrett 2001) advocate.

Inspection Results. Corrective maintenance action reporting is not the only source of information that could be used to drive design decisions. In a given deployment cycle, a ship in the US Navy undergoes a number of inspection, certification, and assist visits that routinely include assessment of system and equipment material condition. In addition, the crew of the ship performs routine preventative maintenance actions that include inspections and data collection relating to the material condition of the equipment. The procedures used in these assessments range from a prepared and automated script, such as that used in assessing the condition of elevators and conveyors, to a series of checklists used by the shipboard training organizations. The procedures differ markedly between organizations, many have no external technical review for accuracy or completeness, and the information collected is fed into a system that resembles not so much a stovepipe as a capped chimney flue. The information is intrinsically valuable to designers, maintainers, and operations planners but is not readily visible to them, in part due to omission of analysis and, even in cases where analysis is completed, termination of the data flow within the echelons of the parent organization.

Assessment Procedures. One key feature not emphasized in the original article is the nature of the assessment procedures. (Chesterman and Garrett 2001) advocate a computer-supported standardized assessment procedure:

> "Standard assessment procedures would be established for use by ship's force and all other activities that would be exactly the same. The procedures automatically would create OPNAV 4790/2K and CK forms to document objective evidence in a structured, configuration-based format"

The hardware for this approach, in the form of pen computers, exists already and supports the elevator assessments mentioned earlier. Technology progresses, so the pen computers will soon be obsolesced by the tablet computers and personal digital assistants demonstrated at some of the more recent technology expositions.

The standardized assessment procedures should include a hierarchical directory-type structure of parent system or equipment "folders" containing subsystem or component "folders" on down to the level required to link the hardware to what (Chelbi and Ait-Kadi 1999) identify as a control parameter. The folders should react in a way similar to that used in accessing the file structure of a personal computer to enable an intuitive use of the graphic user interface. The assessor, a term equally applicable to either a crewmember or a representative of an organization external to the ship, would record the value of the control parameter identified by the assessment procedure. Using a model like that identified by (Chelbi and Ait-Kadi 1999), a mechanism is thereby put in place to provide predictive information, as well as historical information, both of which are invaluable to the maintenance program planners. Reporting data collected in this fashion provides discrete, standardized values that are easily subjected to appropriate analyses.

Standardizing the assessment procedure also ensures the correct data is collected and "charged" to the correct equipment. Given the predictive nature of the model, the assessments would provide their own governing capability, reducing inspection frequency at the beginning of the life span of the equipment or component and increasing the frequency as age-related wear continues. Critical equipment might need to stay on a rigid inspection frequency out of reliability concerns, but the model described by (Chelbi and Ait-Kadi 1999) relates the increased frequency to increased cost, a consideration the author chooses to leave to the holders of the checkbooks.

Such an approach provides additional benefits at the organizational level. The standardized, scripted procedures on a readily portable data collection tool would ensure the technician has in hand an approved procedure to follow, reducing maintenance-induced system failures. In addition, the program providing the script would be able to compare the recorded values to acceptable limits "on the fly," providing the technician with immediate feedback on out of limits conditions, thereby reducing the number of overlooked danger signals. When extended to cover all maintenance actions, the tool inventory and materials required to accomplish all maintenance actions would be available in a centralized, retrievable data format, aiding managers in stock and tool control. All of this combines to maximize efficiency and minimize the workload on already over-tasked crewmembers.

As (Chesterman and Garrett 2001) stated, the information collected would be fed into "A central repository … created for standardized warehousing of material history data to support all stakeholders and customers," including designers and maintenance planners. This ensures historical information has the visibility required to prevent duplication of design errors.

The existing methods of analysis, and some of their shortcomings, have been described already. In addition to the benefits accruing to designers and maintenance planners from well-organized, accessible historical information, linking standardized assessment procedures to a properly structured data warehouse has benefits for operations planners and other managers. Given data correctly exposed in the warehouse, it becomes possible to analyze near-real time data rendered coherent by the imposition of discipline in the data architecture and in the collection method. When the configuration model is correctly tied to mission areas, the analysis could easily replace the existing Casualty Reporting System and TSP in their entirety. Further, it would provide effective filtration for the TMA/TMI program. The concept behind this has already been proven using one of the smaller ships in the inventory as a test platform.

Conclusion

The repetition of design errors is directly related to the visibility, and hence the organization, of historical information. A lack of such visibility may have contributed to the propagation of a design flaw into a second class of ships. The causes of the lack of visibility are linked to a lack of discipline in the data architecture and data collection. Imposing discipline on the architecture and the data collection methods eliminates this problem. The tools exist to correct these deficiencies, requiring only the will and direction to do so. The benefits arising from such action are summarized by (Chesterman and Garrett 2001):

> "A standard, fleet wide view of ship material condition that supports development of a common set of metrics for maintenance resource budgeting and allocation decisions.
> "A universal material condition assessment process across the fleet based on standardized objective evidence.
> "Improved accuracy and drill-down detail in material condition data.
> "Improvements in existing data collection processes rather than starting from scratch.
> "A continuum of assessment process improvement through a feedback loop to the technical and maintenance community.
> "Warehousing of all fleet material condition data in a single database that can be accessed easily and rapidly."

(Talbot 1993), (Degregorio 1999), and (Chelbi and Ait-Kadi 1999) expound on the related issues and help (Chesterman and Garrett 2001) point the way to achieving better designs and eliminating error repetition through improved analysis of historical data.

REFERENCES

Chelbi, A. and Ait-Kadi, D. "An Optimal Inspection Strategy for Randomly Failing Equipment". *The Proceedings of the Ninth Annual International Symposium of the International Council on Systems Engineering.* (Las Vegas, NV, 1999).

Chesterman, C. W., Jr. and Garrett, P. M. "Standardizing Material Condition Assessments". *Proceedings.* United States Naval Institute. Jan 2001; Vol. 127, Issue 1; pp. 91-92.

DeGregorio, G. "Enterprise-wide Requirements & Decision Management". *The Proceedings of the Ninth Annual International Symposium of the International Council on Systems Engineering.* (Las Vegas 1999).

Federation of American Scientists. *Military Analysis Network, DOD-101, US Navy Ships.* Retrieved April 9, 2002, from `http://www.fas.org/man/dod-101/sys/ship/index.html`.

Google. *Google Search Appliance.* Retrieved March 31, 2003, from `http://www.google.com/appliance/index.html`.

Merriam-Webster. *Merriam-Webster's Collegiate Dictionary.* Retrieved April 14, 2002, from `http://www.m-w.com/cgi-bin/dictionary`.

Moorhouse, Dr T. J. "System Faults and Their Diagnosis in Complex Systems". *The Proceedings of the Eleventh Annual International Symposium of the International Council on Systems Engineering.* (Melbourne, Australia, 2001).

Naval Sea Systems Command. *The Configuration Data Managers Database-Open Architecture Online Manual.* Retrieved April 15, 2002 from `http://www.cdmd.navy.mil/pages/ cdmdManualFrames.html`

Office of the Chief of Naval Operations (OPNAV). *Ships' Maintenance and Material Management (3-M) Manual (OPNAV Instruction 4790.4C) Appendix B.* Dated November 7, 1994. Retrieved April 15, 2002, from `http://neds.nebt.daps.mil/4790/b.pdf`

Oxford English Dictionary. *Oxford English Dictionary Online.* Retrieved April 14, 2002, from http://mdusa.lib.umd.edu/proxy/oed/dictionary.oed.com.

Santayana, J. *Life of Reason, Reason in Common Sense.* Scribner's, New York, 1905.

Sloan, Crystal D., *Averting Disaster: Legacy Data and Software Planning.*Retrieved February 24, 2003 `from http://www.ertin.com/pr_legacydata.html`.

Talbot, M. "Why Systems Fail (Viewed From Hindsight)". *The Proceedings of the Third Annual International Symposium of the National Council on Systems Engineering.* (Arlington, Virginia, 1993).

United States Navy. *Naval Vessel Register.* Retrieved April 9, 2002, from `http://www.nvr.navy.mil/nvrships/details/DDG51.htm`.

Biography

Randal Bennett is a graduate student in the Master of Software Engineering program at the University College of the University of Maryland. He owns an independent software consultancy, and he completed over 24 years of service in the United States Navy on February 1, 2002. His Naval experience includes operator, maintenance technician, manager and inspector of steam and gas turbine propulsion systems. His most recent Naval assignment was as boiler and propulsion systems inspector at the Board of Inspection and Survey, Pacific Fleet and prior to that served as Chief Engineer of USS George Philip (FFG 12).

Crystal D. Sloan is a principal of EagleRidge Technologies, Inc., a Rockwood, Tennessee consulting and e-commerce firm, contributor to a number of books on computing, and a recipient of the Microsoft® MVP award. Since 1999, she also works with Dr. William H. McCumber on the development and teaching of Web-based graduate classes. Past projects include development of systems for the space shuttle, medical applications, and radiation monitoring of nuclear plants, many medical laboratory instruments, and numerous business applications. Ms. Sloan holds a S.B. in Mathematics from M.I.T.