**Joseph Famme, Charles Gallagher, and Michel Masse**

# Achieving Human Systems Integration through Design

## ABSTRACT

This paper will describe how Human Systems Integration (HSI) objectives can be achieved by the creation and use of first principle physics models of the ship Hull, Mechanical & Electrical (HM&E) systems throughout the ship "spiral" design process. The models will create HM&E systems performance metrics to verify: engineering throughout all design phases; automation strategies versus manning levels; ship survivability and safety objectives; and support dock and sea trials, and live fire testing. Following trials the validated models and performance metrics will be provided to NAVSEA to support commissioned ships for: school house to total ship embedded training enabling the Revolution in Training and Task Force Excel initiatives; both sailor and HM&E systems performance measurement, readiness assessment, battle decision aids and distance support. The validated physics models can be re-used during ship modernization to verify ShipAlt design and to insure that HSI objectives are maintained. It is projected that the use of these HM&E models also will improve the efficiency of the ship design process and reduce significantly the "over cost" of new ship classes in support of Sea Enterprise.

## INTRODUCTION

Highly robust, highly automated systems that fully leverage human performance are essential in 21$^{st}$ century naval ships. The asymmetrical threat is real, the reaction time short. The human is inefficient at operating and maintaining complex engineering and damage control systems. Past experience has demonstrated that when engineering casualties or damage occurs a human is too slow and vulnerable, and requires enormous logistical and medical support. Aggressive casualty and damage control cannot begin until the humans are accounted for. Reduced crew size requires each crew member to be both better trained and cross-trained. The threat requires that the crew be provided with a survivable environment. Logistically, crew manning is the major life cycle cost driver for a ship. However, humans provide the intelligence necessary for ship mission performance and survival: strategy, tactics, intuition, anticipation, insight, reflection, lessons learned and situational awareness.

The recognition of the value of the human presence aboard ship has lead to the creation of NAVSEA Code 03, Human Systems Integration. The purpose of HSI is to ensure that every ship built and system delivered is designed, acquired and supported with human performance, training, safety and survivability in mind. NAVSEA HSI policy and standards will develop human performance metrics and evaluation techniques.

This paper describes an improved ship design process that uses first principle physics models that when executed at system and total ship levels will provide the human and system metrics required to verify at each design phase that HSI objectives are incorporated into the total ship "system of systems". These models will be re-used in the commissioned ship for embedded training, performance and decision aids, distance support and future modernization. This design environment will also improve the efficiency of the design environment by fully leveraging the design tools of computer aided design (CAD) and physics-based design (PBD) now emerging from new ship programs like DD(X) and through the National Shipbuilding Research Program (NSRP) Integrated Shipbuilding Environment (ISE) research and development efforts.

The authors have named the improved design process a *Transformational Ship Design Continuum (TSDC).*

### Transformational Ship Design Continuum

The term transformation recognizes the Navy imperative of process improvement and the term continuum describes a continuous use of ship design tools from design inception in order to verify that HSI objectives are fully built into the ship before design release to production. The ship mission and HSI verified designs, when captured as real-time dynamic models with associated metrics, can be re-used over the ship's life for HSI objectives of crew training, operational and battle decision aids, distance support and future modernization. For new ships, the TSDC will support HSI objectives from design inception. For existing ships, HSI supporting capabilities must be inserted where feasible.

### HSI Objectives

The HSI objectives to be enabled through design include:

- Training: individual, team, to total ship, ashore and embedded afloat
    - Across engineering, damage control & combat systems
    - Total Ship Training System Roadmap
    - Operator and maintenance training
- Best Practices
- Safety
- Survivability
- Enhanced sailor performance
- Sailor and systems performance measurement and monitoring
    - Support performance metrics and evaluation techniques
- Optimized manpower
- Quality of service
- System of systems approach
    - Hardware, systems and people
- Systems engineering
- Distance support

In addition to verifying that HSI objectives are achieved during design, the physics based modeling metrics also will provide support to Sea Enterprise by improving efficiency in the design process, thus freeing money to apply to HSI initiatives and improve combat capability.

### Seapower 21 - Sea Enterprise Initiative

The Sea Enterprise initiative states that:

*"We will improve business practices to achieve end-to-end capabilities in the most economical manner. These business practices will focus on continuous process improvement with metrics for measurement and evaluation"*

In the FY2004 US Budget, the Office of Management and Budget (OMB) performed a business process efficiency analysis of the US shipbuilding industry and found that for the first of class Navy ships, the average "over cost" is 30% (White House 2004).

Based upon the LPD 17 and similar modeling experience, the authors estimate that the use of the performance metrics provided by HM&E systems models to verify engineering to performance requirements during the design process will improve shipbuilding efficiency and reduce over-cost significantly.

## SHIP DESIGN TOOLS THAT ENABLE HSI

In order to verify HSI objectives during design it is necessary to develop dynamic, real-time physics based design (PBD) models, integrated with computer aided design (CAD) tools. These models will be used to provide the reference metrics needed to measure HSI based HM&E systems and personnel performance. This section will describe these tools.

### Physics Based Design

The development of PBD tools – the use of first principle physics models (equations) to represent the HM&E components and systems - has progressed significantly in the past ten years. PBD is usually the domain of professional engineers who may use mathematical models. As computer capabilities improved these models were implemented in spreadsheets and other analytical representations to verify designs before release to production.

In the field of PBD tools there have emerged two complementary capabilities. One is the single discipline design tools. The other is the multi-discipline design analysis tools.

### Single and Multi-Discipline PBD

Single discipline tools are used primarily to conduct static and transient analysis of a single engineering discipline such as electrical, liquid, gas, or HVAC, and are used to select, size, calibrate and find faults in component and subsystems design. The single discipline tools often do not run in real-time, nor do they need to.

The multi-discipline PBD tools permit simultaneous modeling and analysis of the disciplines of electrical, liquid, gas, or HVAC and associated controls. These tools are most often run in real-time or faster than real-time to conduct design analysis in and across interdependent HM&E systems including associated controls.

The two disciplines are compatible in that single discipline selected component models can be transferred to the multi-discipline tools to be tested in and across the total systems to the total ship level, thus verifying that all HM&E systems meet HSI and mission requirements as a system of systems. TSDC uses multi-discipline tools to verify that single systems up to a complete ship HM&E design meet HSI, operational, and survivability requirements before the designs go to production.

### Static and Dynamic PBD

Another attribute of PBD is the difference between static and dynamic design analysis. Static analysis is conducted in a steady state environment. Dynamic analysis is conducted to evaluate transient performance. It is now possible to drag and drop object models of ship HM&E components on to a screen, connect them together forming system block diagrams and compile the system into run-time where the system can be observed working in real-time or at a faster or slower time step. The engineer can select case scenarios containing any combination of values for observation or recording and import the computed results to spreadsheet tables and graphs for analysis. The TSDC process uses dynamic modeling.

### Computer Aided Design (CAD)

CAD is the process of producing dimensionally accurate, 2D drawings and 3D models of ship systems as a replacement for paper drawings. CAD performs the essential functions of proving that all ship components are properly located to not interfere with any other components, meet verification society rules and to assist ship production in manufacturing parts.

*CAD proves that systems "FIT"*

*PBD proves that systems "WORK"*

### Electronic Data Integration: PBD – CAD

Data integration (exchange) between design tools is a key technology of TSDC. This means

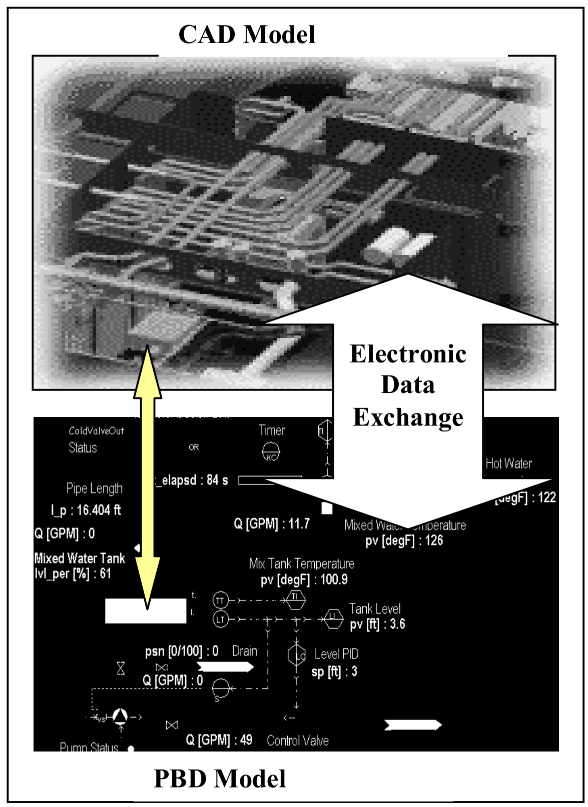


**Figure 1 Electronic Data Exchange**

that whether a shipbuilder begins their design in a CAD or PBD environment that the object data exchange is fast, accurate and always in synch. In Figure 1 the smaller arrow (top end) shows a tank in the dimensionally accurate CAD 3D drawing pointing to the functionally accurate model "ICON" for the physics equation of the tank. The requirement to integrate and demonstrate CAD and PBD electronic data exchange is being met by parallel programs:

- National Shipbuilding Research Program (NSRP), Integrated Shipbuilding Environment (ISE) data exchange
- The DD 21, now DD (X) program, CAD to PBD data exchange development.
- National Institute of Standards and Technology (NIST)

### PBD Object Couplings

It is important to know how the physics models are linked when simulating the designed systems. As defined by Dougal (2002) there are three types of physics object couplings.

#### *NATURAL COUPLING*

"… when interactions require enforcement of physical conservation principles" such as Bernoulli's and Kirchoff's laws. The "nature" of an element may be "electrical", "thermal", "mechanical", etc. Associated with the connection is the concept of "through" and "across" variables. The "through" variable is "flow-like" and the "across" variable is "potential-like". For example, because the flow is a function of the pressure drop and the pressure loss is dependent on the flow, it is necessary to solve the equations simultaneously, or to iterate until the terms are in agreement. Natural coupling is appropriate and preferred for the TSDC modeling tasks to support HSI objectives described in this paper.

#### *SIGNAL COUPLING*

"… the directed flow of information through objects." A computational block accepts some data input and executes an operation to produce an output. Signal coupling is typically used to model process (machinery) control systems.

#### *DATA COUPLING*

"Pass data between objects." This method is simply the transfer of information from one object to another whether or not they are collocated.

### Other Integrated Ship Design Environments

There are three other design environments that the authors will mention quickly:

- LEAPS (Leading Edge Architecture for Prototyping Ships) developed and used by NAVSEA (Hurwitz, 2001)
- LPD 17 Integrated Product Data Environment (IPDE) and Modeling & Simulation Program developed and used for the LPD 17 program (Murphy, 2001)
- The Synthetic Carrier design environment program developed by Newport News Shipbuilding (Lisle, 2001)

All three use a combination of integrated product design environment data repositories, 3D visualization, and tools including CAD and PBD modeling from a variety of sources. None of these systems envision creating a complete ship dynamic model to provide the HSI performance metrics for use aboard ship proposed for TSDC. However, the TSDC model creation process can be used intact within any of these three design environments.

## THE TRANSFORMATIONAL SHIP DESIGN CONTINUUM

This section discusses how TSDC models will fulfill HSI objectives as a continuing by-product of the ship design process. Also described will be the extent to which the capability currently exists or could be made to exist with investment and will be followed by a business case example.

### TSDC Enables HSI Metrics

The full advantages of TSDC are achieved by rolling up the dynamic models (metrics) periodically throughout the design phases to verify the design at its current phase. This permits "operating" the virtual ship according to the planned doctrine to verify that the design, in the current design phase, meets the HSI objectives to the extent the model is complete.

### TSDC Phases

Table 1 lists the TSDC process phases. Phase I contains the steps that design, test and deliver the ship. This phase builds and calibrates the HM&E systems models with associated metrics. Phase II is the delivery of the ship and delivery of the dynamic physics models to NAVSEA and to the fleet. Phase III is the re-use of the physics models to provide via HM&E simulation performance metrics that support the operational lifecycle of the ship.

**Table 1 TSDC Process Phases**

| |
|---|
| **Phase I: Ship Design, Build and Test** |
| 1. Ship Requirements & Design Environment Selection |
| 2. Concept Design |
| 3. Preliminary Design |
| 4. Automation Design |
| 5. Contract Design |
| 6. Detail Design |
| 7. Ship Survivability and Casualty Control Doctrine Analysis |
| 8. Ship Systems Operating Doctrine |
| 9. Ship Operational Concept |
| 10. Construct Ship |
| 11. Tests & Trials |
| 12. Live Fire Testing |
| **Phase II: Deliver Ship & Models** |
| **Phase III: Ship Lifecycle Support** |
| 1. Embedded Training Afloat |
| 2. Training Ashore |
| 3. HM&E Decision Aids |
| 4. System Performance Metrics |
| 5. Distance Support |
| 6. Ship Modernization |

As the ship design models are “run” dynamically they are tuned to meet the operational and HSI performance requirements in and across all HM&E systems. The models are validated during ship tests and trials. These validated PBD models within a single data environment then provide the performance metrics that enable HSI objectives to be met because the models replicate the operational performance parameters of the HM&E systems and therefore the metrics needed to determine whether or not the operational systems and the crew are performing as designed.

## How TSDC Enables HSI Metrics

The PBD models include the system *operating parameters* (temperature, pressure, amps, voltage, volumes, flows, stability…) and *timing* of systems operations. The validated models are captured for re-use over the full operational and training life of the ship. These models provide the validated reference metrics that are essential for efficient designs and enabling of HSI objectives. The validated HM&E systems models will be installed on the ship to “run” in parallel with the operating ship HM&E systems.

## Phase I Ship Design, Build & Test

### *SHIP REQUIREMENTS & DESIGN ENVIRONMENT SELECTION*

This phase represents the selection and acquisition of suitable computer design tools for CAD and PBD, and establishment of ship specifications. As needed, abbreviated models can be created during this phase for comparative analysis.

### *CONCEPT DESIGN*

PBD tools are ideal for modeling the array of designs and analyzing through simulation the alternatives such as crew size, automation, propulsion, survivability, operating doctrine and casualty control.

### *PRELIMINARY DESIGN*

PBD models created in the Conceptual Design phase can be readily exchanged electronically and modified and expanded to add more detail for the purpose of conducting trade off studies. These studies may include attributes such as cost and weight, as well as rapidly compare different designs for survivability, automation and manpower.

### *AUTOMATION DESIGN*

Automation Design is a design phase that shipbuilders tend to subcontract to third parties. To achieve a high level of HSI objectives the manpower vs. automation control strategies must be designed in and verified through each design phase, as well as during test and trials and live fire testing. This is accomplished in the TSDC by PBD modeling of the HM&E systems with their associated controls and modeling the human event or time based engineering and damage control procedures. The automation scenario is then "run" and the response of control system and human actions (or failure) are analyzed. Significant costs savings are achieved because the automation model drives from previous design phases and does not have to be recreated just to support the control system design as is now the process.

### *CONTRACT DESIGN*

The purpose of Contract Design is to refine the selected design with full definition of performance and HSI metrics. This is a perfect case where PBD models can be expanded for comparative performance analysis and then be signed off as the ship "specification" as all of the HM&E system and component performance parameters are accurately captured electronically.

### *DETAIL DESIGN*

Begins at award of construction and includes analysis of distributed systems and drawings. At this point the CAD / PBD models can be updated though the IPDE, and periodically re-run to insure that HSI and operational objectives are maintained. As an example, on LPD 17, in order to validate that the chilled water would perform correctly, dynamically, under numerous conditions such as in-port, underway, different material conditions and casualties, the Navy specified "running" dynamic scenarios. As a result of dynamic modeling changes were made to the design.

### *SHIP SURVIVABILITY AND CASUALTY CONTROL DOCTRINE ANALYSIS*

The TSDC will include co-spiral design with co-spiral analysis. This is possible because the PBD models seamlessly expand from low to high detail, with fully documented and configuration controlled HM&E models. At periodic intervals during the design process the engineers can conduct trade-off studies and verify that the selected survivability designs, with associated controls and casualty procedures, are in fact capable of meeting the specified ship mission and HSI objectives.

### *SHIP SYSTEMS OPERATING DOCTRINE*

Operating doctrine for the engineering and damage control systems is closely coupled to crew size, complexity of the plant and level of automation. Key elements of the Engineering Operational Sequence System (EOSS), Engineering Operational Casualty Control (EOCC) procedures, Damage Control Procedures, and Combat System Operational Sequence System (CSOSS) should be considered at this stage of design to insure that the resulting design, from day one, truly supports the Navy operational and HSI requirements including human machine interfaces. PBD tools can rapidly "prototype" HM&E conceptual designs that can be "operated", starting with simple versions of systems, and then be expanded over time with additional detail as more is known including the impact of the demands of the other HM&E systems as they are linked together into a complete ship virtual model.

### *SHIP OPERATIONAL CONCEPT*

The TSDC environment lends itself to not only spiral design for engineering, but also spiral development of the ships concept of operations. This insures that engineering design is continuously evaluated to support HSI objectives within the proposed concept of operations over the range of missions anticipated. The Littoral Combatant Ship (LCS) envisions a mix of exchangeable sensor-weapon system modules. Will the LCS HM&E plant be able to support the auxiliary requirements of every combination of modules employed? Are manpower and automation in balance? This analysis considers the redundancy and survivability of the HM&E components and systems through *dynamic* validation using real-time simulated operations and battle damage.

### *CONSTRUCT THE SHIP*

The ship construction phase, which overlaps some of the previous phases, is expected, based upon previous experience, to have far fewer change orders and "over-cost" as a result of continuous modeling for design verification prior to release to production.

## *TESTS AND TRIALS*

The tests and trials organizations of major shipbuilders are now becoming aware of the existence of models of HM&E systems. Some test and trials organizations in order to reduce program costs are planning to use the PBD models for a baseline of systems performance that they should see on the real ship during dock and sea trials. Real-time models of the HM&E systems will be created during design to verify the performance objectives including timing. The performance data is collected in Excel spreadsheets by operating case. During dock and sea trials the same test cases can be implemented and the actual performance values can be entered next to the modeled values to verify that the actual ship systems meet performance specifications. Differences can then be resolved by correcting the model or the ship systems. This validates the ship systems and the model to the performance specifications. This validated model forms the basis for future shore and afloat training, performance assessment, decision aids, distance support and future ShipAlts.

## *LIVE FIRE TESTING*

The FY97 Defense Appropriation included congressional funding to investigate alternative uses of simulation and training technology to support Live Fire Test and Evaluation (LFT&E). Live fire testing is unique in that, apart from actual combat, it is the only source of realistic combat vulnerability and lethality data. It evaluates battle damage repair procedures and estimates of user casualties. This program takes that realistic data and combines it with training technologies and opportunities in a synergistic way.

Ideally a production ship will be exposed to "enemy" fire to see whether or not the self defense / safety equipment is able to protect the ship and its crew, and if not why not. Starting fires to validate the fire spread assumptions or holing the ship and its compartments to validate progressive flooding cannot be "tested" live on a production ship. Enter the value of PBD models. Navy Battle Damage Estimator (BDE) effects can be inserted in the dynamic, real-time HM&E and simulated crew models. The cascading damage can be observed in the model as well as the application built-in control systems automation and simulated crew application of EOSS / EOCC / CSOSS procedures. The models can provide a likely result to augment LFT&E where test to destruction is not possible.

## PHASE II: DELIVER SHIP & MODELS

The ship is delivered to the Navy and the validated dynamic models can be delivered to Type Commanders and Afloat Training Groups to support the ship's operations over its lifecycle for incorporation into training systems, systems performance monitoring and readiness evaluation, distance support and future ship modernization.

## PHASE III: SHIP LIFECYCLE SUPPORT

TSDC models created and validated during the design phase will be available in the life cycle phase to support HSI objectives. The authors expect the cost of the TSDC design tools and their integration will be offset by the savings in the design, build and test phases by a factor of at least 5:1 (see business case). Thus it is expected that the underlying models that support HSI objectives in the operational life of the ship are essentially "free." In as much as each of the following operational logistics requirements requires a dynamic metrics model the synergistic value of the models should be substantial.

## *EMBEDDED TRAINING AFLOAT*

The use of real-time models for the HM&E systems permits, for the first time, the engineering and damage control operators and teams to experience the same high fidelity of training that is now standard for combat systems training. There can hardly be a higher priority for training than improving engineering and damage control training. The Navy has experienced catastrophic damage to its ships in the past 12 years, nearly losing at least two. A lesson learned from the USS Cole bombing was that the HM&E systems might have failed had not other ships come to the rescue and the crew exerted heroic efforts. No crew is prepared for the speed of cascading damage seen in modern damage events because there are no HM&E training systems in the Navy that can provide the real-time, two sided, interactive training for engineering and damage control considered standard for combat systems training. The Commander Naval Surface Forces Pacific (CNSP) identified this shortfall in fleet engineering and damage control training in a report on training and readiness in February 2002.

A prototype total ship training system incorporating a real-time HM&E ship model linked to the BFTT model addressing the CNSP shortfall was demonstrated under an SBIR Phase 2 contract in 2002 (NAVSEA PMS430 2001.

### *TRAINING ASHORE*

Task Force Excel, which has the charter to improve sailor training from the school house to the ship and onboard the ship, asked the question: Could the physics models demonstrated during the Navy SBIR Phase 2 program at the whole ship level for total ship training be decomposed into specific engineering and damage control systems models complete with associated machinery control systems HMI control pages? Yes. In fact the prototype model was, and the proposed TSDC complete ship physics model could be decomposed into models of individual engineering systems (electric plant, chilled water, HVAC). Each of the EOSS / EOCC / CSOSS lesson plans can have an underlying model that will support time-based, interactive, performance/metrics based training. The students can experience damage and restoration processes that may be too dangerous to perform with live equipment.

### *HM&E DECISION AIDS*

As crew size is reduced and automation increased it is important that the crew be provided operational and battle decision aids. The HM&E decision aids are created by accessing the TSDC models. As demonstrated with the NAVSEA SBIR prototype total ship training system, the models can be designed to represent HM&E systems and compartments including progressive flooding, fire and smoke spread. This permits the crew to train against dynamic models so that time (especially time late) is always a factor. In operational and battle environments these same models, with inputs from the ship's control systems and the crew, also can be used to decide on future courses of action. During the SBIR demonstration, compartment progressive flooding was calculated and the weight moments entered into a ship stability model provided by the Naval Postgraduate School to calculate drafts and GM calculations. The models can also be interfaced to the Navy Flooding Casualty Control System (FCCS) and the future Hull Structural Strength System (HSSS) to provide the crews with a complete training system as well as "what if?" decision aids for use in operational situations. The physics models can be "run" faster than real-time so that sensitivity analysis can be made on the sequence of de-watering, for example. The model can also accept inputs of expected damage from the Navy Battle Damage Estimator models. This permits verification of survivability during design and also "what if" decision aids.

### *SYSTEMS PERFORMANCE METRICS*

The essential requirement of accurate performance monitoring of HM&E operations is the use of verified system and operator performance metrics. TSDC expands the existing capability for equipment monitoring systems like the Integrated Condition Assessment System (ICAS). ICAS is an excellent system that focuses on the metrics and monitoring of individual equipment. From a command point of view, the health of a single item of equipment is necessary. But what are the command options at the systems level? Are there system level options to continue operations and what is the risk? For systems performance monitoring a signal to the plant is a signal to the model. The output of the model and the plant should remain in synchronization within defined metrics limits. If the metrics variance is outside the limits or even trending to go outside the limits, the operator is notified. In the DARPA Platform Readiness Operator Assistance program (PROA - DARPA 1993-6) three options were provided to the operator. The automation systems will pick option A unless the operator overrides and selects option B or C. If the operator had been incapacitated due to battle damage, then the automation sequence would select option A. The threshold for notification will change as the mission of the ship changes from in-port to peacetime cruising to war time cruising.

### *DISTANCE SUPPORT*

The advent of smaller crew sizes where there could be a loss of critical skills has led NAVSEA to develop the support system called SEA Enterprise "Distance Support." For effective distance support the shore team must have metrics of the performance of ship HM&E systems and be able to compare the metrics to standards for correct system operation under the same operational circumstances. TSDC will reuse the real-time validated physics models as discussed in the performance monitoring paragraph. When distance support comes in to reality the models would be installed in the ship as well as at NAVSEA. As needed, communications would be established between the ship and the NAVSEA facility. Depending on policies in effect, NAVSEA would be able to access the ship HM&E sensors as well as the output of the ship model. NAVSEA would be able to compare the ship model and plant "conditions" to the model at NAVSEA as a means to diagnose and recommend a fix to ship problems. As in PROA, certain decision aids can be built in to the model.

### *SHIP MODERNIZATION*

The TSDC use of models to support HSI objectives in the design of new ships is applied equally for the modernization of existing ships. For new ships, the TSDC will support HSI objectives from design inception. For existing ships, HSI supporting capabilities must be inserted where feasible. However, as demonstrated for the CG 47 AAW Commander Modernization program, PBD tools were used to create models of the as-built electrical, firemain and chilled water systems to analyze the impact and size the proposed modernization ShipAlt based on the capability on the ship's existing systems. TSDC models may be used during modernization to design new machinery control systems as well as to repair deficiencies in the original ship systems that have not performed as required since the ship was built. There will also be the opportunity to support many HSI objectives such as embedded training, performance metrics and monitoring. Each ship class would be reviewed to see which systems should be modeled for HSI purposes.

## A BUSINESS CASE FOR THE TSDC

A TSDC that provides all of the HSI benefits discussed may be viewed as expensive. Can the Navy afford it? The better question is can the Navy afford not to use the TSDC processes? This section will provide a review of likely cost savings potential and likely costs to perform verification modeling. What are the cost drivers for shipbuilding inefficiency?

### COST TO CORRECT

A major inefficiency is cost-to-correct as describe by current thumb rules within the shipbuilding industry such as the 1:3:5 anecdote. If it costs $1 to make a change in the shop, it costs $3 to make the change during erection and $5 to make the change with the ship in the water. Another shipyard has a thumb rule of 1:4:8. With little real shipbuilder data the authors turned to formal data on the cost to correct 4200 corrective actions from NASA (Lewis, 2002). Figure 2 is Log Scale data that seems to confirm that continuous design performance verification

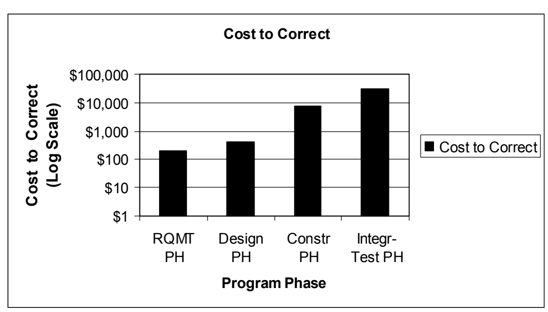


**Figure 2 NASA Cost to Correct**

provides potentially large program cost savings through reducing rework. The authors experienced similar savings using modeling tools in the design phase of LPD 17, the first Navy program to formally use both CAD and PBD extensively. PBD was used to verify nine of some 25 HM&E LPD 17 systems.

## THE LIKELY COST OF TSDC CONTINUOUS VERIFICATION MODELING

As in the Cost to Correct discussions there is little available data in the shipbuilding industry to guide decision makers about the investment cost to insure that engineering and designs are routinely performance verified. However, NASA has generated a likely cost model based on 18 programs (Shuemaker 2002). The NASA data suggests that the cost would be about 5% of the design costs (TSDC Phase I). The NASA costs are for a full Independent Verification and Validation that may cost more than a TSDC recommended policy of continuous performance verification modeling. The authors believe based on experience with LPD 17 and modeling on more than 20 classes of Navy ships, combined with the emerging technology for data integration proposed for TSDC, that verification modeling will return savings on the order $5 to $10 for every dollar invested in the TSDC.

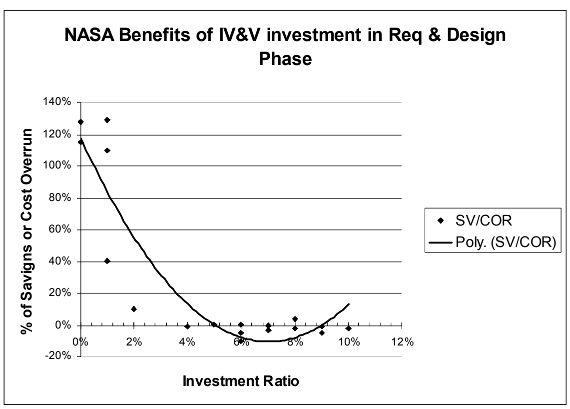


**Figure 3 NASA Likely Cost for IV&V**

## LIKELY COST SAVINGS USING TSDC

Table 2 was constructed by the authors based on modeling experience including LPD 17 and twenty other Navy ship designs, commercial industry use of modeling and consideration of the NASA data. The example used is for a destroyer size ship with a high end estimate of 80,000 HM&E objects to be modeled incorporating all of the HM&E systems individually and rolled up to the complete ship model. This table is based upon conservative estimates and derives a net program cost savings by using the TSDC processes starting in the conceptual design phase.

**Table 2 Cost Savings by Program Phase**

| Costs by Program Phase ($M) | | | |
|---|---|---|---|
| Program Phase | Non-Recurring Cost Today ($M) | Percent Change | Non-Recurring Cost Savings ($M) |
| Ship Requirements | Provided | | |
| Concept Design | $50.0 | -6% | -$3.0 |
| Preliminary Design | $200.0 | -10% | -$20.0 |
| Automation Design | $10.0 | -40% | -$4.0 |
| Contract Design | $200.0 | -10% | -$20.0 |
| Detail Design | $500.0 | -10% | -$50.0 |
| Construction First Ship | $550.0 | -5% | -$27.5 |
| V&V-Tests-Trials-Live Fire | $70.0 | -10% | -$7.0 |
| Training Afloat - Ashore | $25.0 | -30% | -$7.5 |
| Decision Aids | $10.0 | -50% | -$5.0 |
| Distance Support | $10.0 | -30% | -$3.0 |
| Modernization ShipAlts | $100.0 | -30% | -$30.0 |
| | $1,725.0 | Savings | -$177.0 |

The savings are projected based on the following factors:

- Savings shown are net after the cost of creating verification models in the 5 design phases
- the ability to rapidly create and iterate design model alternatives that satisfy operational and HSI objectives
- the capture of all design data for reuse in a standard, electronically transferable formats
- the requirement to verify that designs "work" before they are approved for the next phase,
- the reduction in the cost to correct accounts,
- the achievement of HSI objectives throughout the design phases of the ship.
- the creation, validation and use of performance metrics essential to achieve HSI objectives in the operational phases of a ship's life
- the reuse of design models for HSI objectives of automation, training, performance monitoring, readiness assessment, distance support and future modernization

# CONCLUSIONS

The authors suggest that the full achievement of human systems integration objectives requires a continuum of effort from ship requirements definition, executed through integrated design processes, and reused as validated design model metrics throughout the total life of a ship. Real-time modeling is the key technology because the models provide the systems verification and the performance metrics that are essential to meet HSI objectives. The authors appreciate that other approaches to improving design processes are in development because at the end of the day these other processes also come to the realization that physics models must be developed. This is the only method to create HSI supporting metrics.

It appears to the authors that the Navy and industry have not achieved a metrics based ship design continuum because it is all too easy to focus on the individual phases in design and lifecycle support and not see, and therefore not treat, the design and lifecycle phases of a ship as a holistic continuum. A top level policy is needed that requires supporting HSI through the entire ship life, from design to logistics (life cycle support). NAVSEA has recognized the need to improve HSI across the Navy and has chartered SEA 03 for this purpose. The question then is will SEA 03 have the support necessary to bring ALL elements of the shipbuilding process together?

Comprehensive achievement of HSI objectives can be met only with a holistic view. All of the phases of a ship's life must be interwoven. If the Navy takes the holistic view then it will also be possible to apply "efficiency" standards to the shipbuilding process. A 30% average "over cost" for the first of class ship is unacceptable when technology described in the TSDC is available. The OMB note to fix the problem by raising the cost estimate rather than fixing the process also seems unacceptable. This is particularly true when the TSDC process wraps in the HSI objectives AND shows the potential to reduce the average "over cost."

There is no cost, only cost savings, in implementing TSDC if the Navy policy looks at the design and HSI processes holistically because the cost of modeling to create the metrics is off-set by efficient design processes and reduction in cost to correct accounts. However, in today's environment, the shipbuilder's view is that the cost of the design tools and modeling must be absorbed in the early phases of the design process, and that because of accounting rules, neither the savings in the current nor subsequent phases can be credited toward the initial costs to acquire CAD, PBD and data integration tools. This myopic view prevents achieving OMB desired "efficiency" in shipbuilding and compromises the Navy's ability to achieve HSI objectives because the design performance metrics are forever disassociated from the HSI models and metrics required for training, performance measurement and decision aids, distance support and future modernization.

## REFERENCES


Dougal, Roger, University of South Carolina, Virtual Test Bed, *Overview of the 2002 Annual Review*, July 2002

Hurwitz, Myles, NSWC, LEAPS, at 5th Technical Interchange, Navy Modeling and Simulation Office, May, 3, 2001

Lewis, Robert O. (1992), Independent Verification and Validation: A Life Cycle Engineering Process for Quality Software. Session A1, Foundations 2002, Johns Hopkins, October 22-23, 2002.

Lisle, Rob, Newport News Shipbuilding, at 5th Technical Interchange Navy, Modeling and Simulation Office, May, 3, 2001

Murphy, Jim, LPD 17 IT, NAVSEA, at 5th Technical Interchange Navy, Modeling and Simulation Office, May, 3, 2001

Shuemaker, Randall, UCF Institute for Simulation & Training, Foundations 2002, Johns Hopkins, October 22-23, 2002.

White House 2004 www.whitehouse.gov/omb/budget/fy2004/pma/shipbuilding.xls


## ACKNOWLEDGEMENTS


Thank you to Ted Raitch and Dimitri Tsingakis for references and proof reading.


---

**Joseph B. Famme** *is the principle author and president of ITE Inc., an engineering and technology consulting firm. He has a BS Degree in Industrial Management and Masters Degree from the Naval War College. Cdr Famme served as a surface warfare officer with command of a Knox Class Frigate. Ashore he served as training systems acquisition specialist in the design and procurement of modeling and simulation systems. In industry with Singer Link and CAE Electronics he worked in the development of tactical and embedded ship training systems as well as automated machinery control systems for ships such the first SmartShip, USS Yorktown (CG 48) and LPD 17.*

**Charles Gallagher** *graduated from the United States Naval Academy in 1961, served nine years on active duty, and retired from the Naval Reserve in 1991. Upon leaving active duty he joined Litton Industries, which was acquired by Northrop Grumman in 2001. He spent 18 years in Engineering, including ten years as the Chief Combat Systems Engineer. He was the technical manager for the construction of three SA'AR 5 Class Corvettes for the Government of Israel and the manager of the Flight IIA upgrade on the DDG 51 Class. Currently he is the manager of advanced programs for the Full Service Operations business unit in Northrop Grumman Ship Systems.*

**Michel Masse,** *president of SIMSMART Inc. has more than twenty years experience in the development of large scale commercial process control systems for pulp, brewing and pharmaceutical companies. SIMSMART™ has been used in naval shipbuilding as a naval ship physics based design tool for the past twelve years and has been demonstrated for use as a simulation model for shipboard embedded engineering and damage control training networked to the Battle Force Tactical Trainer (BFTT) and to the Damage Control Action Management System (DCAMS). Mr. Masse has been instrumental in the incorporation of open architecture and commercial off the shelf technologies.*