Performing Detailed Design Reviews of a U.S. Navy Surface Combatant within an Integrated Data Environment

G. R. Grogan E.I., Naval Sea Systems Command (AM)
J. L. Borthen E.I., Alion Science and Technology, Naval Architecture (AM)

Between November 2006 and March 2009, the U.S. Navy's first Zumwalt class Guided Missile Destroyer, DDG 1000, underwent Detailed Design. According to a Government Accountability Office shipbuilding study in 2005, late changes to a ship's design is recognized as the primary factor contributing to increasing ship construction costs. Therefore a strict Detailed Design review process was implemented for DDG 1000 that included improved Computer Aided Design tools and more efficient communication methods than previous ship Detailed Design efforts. The actual benefit of the design reviews of the Zumwalt Class will not truly be known until after the Lead Ship has been commissioned, however, the design reviews, along with the unprecedented involvement by stakeholders via an Integrated Data Environment, have already proved to be an effective means for reducing the probability that setbacks will be encountered at the waterfront.

KEY WORDS:

DDG 1000; Detailed Design; Naval Ship Design; Integrated Data Environment.

INTRODUCTION

DDG 1000 is the US Navy's 21st Century surface combatant. It will operate closer to shore than the previous class of guided missile destroyers, taking advantage of innovative stealth technology and cutting-edge radar systems. The ship will employ significantly less manning and more automation than previous Navy destroyers and will possess an Integrated Power System, a Total Ship Computing Environment, more efficient gun systems, innovative missile capabilities, a composite deckhouse structure, helicopter/VTUAV support facilities, and a completely enclosed small boat stern launching system designed for 11 m RHIBs. This large quantity of new technology along with recent improvements in computer design software and communication methods warranted the need for a controlled Detailed Design process that would take advantage of these newly available resources.

A BRIEF HISTORY OF DETAILED DESIGN

DDG 51

The Detailed Design effort of the ARLEIGH BURKE class of Guided Missile Destroyers took place between 1985 and 1989. "In 1985 Bath Iron Works (BIW) and Gibbs and Cox planned to execute detailed design for DDG 51 in 3D CAD. However, the necessary resources and capabilities did not exist to successfully complete the plan and BIW reverted to manual design" (Schmidt 1990). The design was developed by hand-drawing each of the ship's systems on Mylar sheets, distinguishing ship systems from one another via different colored-pencils. Obviously, this method did not lend itself well to making alterations to the design. In addition, 2-D drawings often required a large number of annotations and written clarifications to adequately convey information.

It was not until Flight IIA, in 1990, that the DDG 51 class began using 3-D Computer Aided Design (CAD) software. The tools of the day made it difficult and in some cases impossible to eliminate all interferences which became manifest during construction, often leading to local redesign, ripout and rework. Compounding the interference problem was the amount of field-run pipe and vent, runs that were shown on drawings as general guidance only and the shipbuilders determined the exact location as the pipe or vent was installed. The introduction of 3D CAD allowed for significant improvement in elimination of interferences and aided in improved visualization of the overall arrangement of compartments, leading to superior layouts. As 3D CAD tools improved, more detail could be included, reducing the need for field-run systems to the extent that today field-run systems can be completely eliminated. These improved tools also allowed the Navy to review the detail design progress throughout the design period, ensuring Navy involvement when design decisions needed to be made and that specifications were met (or exceptions granted as required).

The two most enduring obstacles that were encountered when CAD was first introduced were a lack of computing power and an incompatibility between different computer programs. For the DDG 51 Flight IIA, "Bath Iron Works [used] Computervision for outfit and AUTOKON for structure; Ingalls Shipbuilding [used] Calma for outfit and SPADES for structure" (Schmidt 1990).

Also during the Detailed Design phase of DDG 51, the Navy (i.e. the customer) was not intimately involved with the development of the design. For the most part, the design drawings were complete before the Navy was able to review them. Had customer reviews of the design occurred in parallel to the design development, the $1.25 (GAO NSIAD-90-84

1990) billion lead ship construction cost may have been significantly less*.

LPD 17

The first of the LPD 17 class of U.S. Navy amphibious ships was built in Louisiana. During the Detailed Design phase of the LPD 17, a 3-D CAD model was developed and Navy representatives critiqued the design via face-to-face meetings. Meeting in person can often become time-consuming and expensive and many of the people that worked on LPD 17's Detailed Design effort were even required to relocate closer to the shipyard in order to be more readily accessible.

SSN VIRGINIA Class

The VIRGINIA Class submarine program utilized visualization methods that enabled a broader scope of involvement and facilitated the resolution of questions and comments within a much shorter period of time than that of previous Navy ship acquisition programs. The VIRGINIA Class program did not have individual zone reviews like that of DDG 1000, but rather they held weekly progress reviews and periodically the shipyard would host "in-depth reviews of the overall design and construction" (General Dynamics 2002).

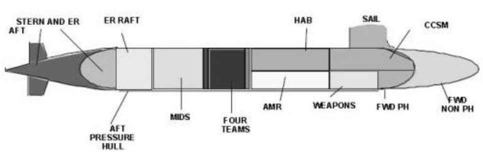

Fig. 1: VIRGINIA Class Major Area Teams (General Dynamics 2002)

"The VIRGINIA had 50% of the construction drawings issued before start of construction versus only five to six percent for [the prior submarine class]" (General Dynamics 2002).

CVN 78

The first of the GERALD R. FORD Class of Nuclear Aircraft Carriers is currently being built in Newport News, VA. They have had extensive modeling in a 3-D CAD environment, specifically CATIA. The carrier's design information has been archived in ENOVIA, a "lifecycle application for product data and lifecycle management and decision support" (IBM Press Release). The CVN program also utilized a Computer-Aided Virtual Environment, or CAVE, which was a 3D immersive environment tool used to literally walk around inside the product model.

T-AKE

The T-AKE class of U.S. Navy supply ships underwent Detailed Design beginning in October of 2001. Computer Aided Design was a central part of the T-AKE design effort. The Detailed Design Reviews of T-AKE were performed by the Navy away from the Design Agent's locale and without the Design Agent's complete participation. Flaws and inconsistencies found in the design were documented with written problem descriptions and where they were located. These comments were then "snail-mailed" from the Navy's design site on the east coast to the shipyard in California. The responses were then mailed back, sometimes months later.

THE REALIZATION OF NON-CENTRALIZED INFORMATION

T-AKE and CVN 78 paved the way for non-centralized design reviews, in which a subject-matter expert could review product models and/or zone drawings at his or her convenience and from any location with an authorized computer. The tool that makes this possible is the Integrated Data Environment (IDE). An IDE is a shared, user friendly interface between a server computer and the people that need access to the information on that server. Utilizing an IDE as a means of centrally locating the information used during Detailed Design and to support non-centralized reviews has, up until recently, been unattainable due to limitations in computing power, budget, and support logistics. DDG 1000 overcame these limitations and IDE-based design reviews were implemented effectively.

DDG 1000's IDE was created during Phase III (Functional Design) of its acquisition plan. The IDE consisted of two main components known as TeamCenter Community and TeamCenter Enterprise. TeamCenter Enterprise focused on the life cycle management by archiving baseline drawings, change documents etc. TeamCenter Community was the working level component created to organize and store documents such as Functional Design briefs, System Integration documents, contractual documentation, etc. Documenting important information was essential to avoiding miscommunications and disagreements. The IDE as a whole, in effect, became an archive and repository of the design's maturation and iterations.

The DDG 1000 IDE was incorporated into the day-to-day tasks of the Program to a much greater extent than previous Navy Programs. Considering the amount of information that was archived daily, finding specific information in a timely manner, had the IDE not been created, would have proved to be extremely difficult. Information was saved to logical locations in the IDE and was linked together to provide a secure neural network of documents and data.

During Phase IV (Detailed Design & Construction) the IDE became a home for all the information related to the Zone Design Reviews.

The most valuable feature of the IDE, as mentioned earlier, was the ability to freely send and receive information in a

* Assuming a 4% inflation rate per year between 1985 and 2009, the ARLEIGH BURKE's construction cost would currently amount to roughly $2.45 billion.

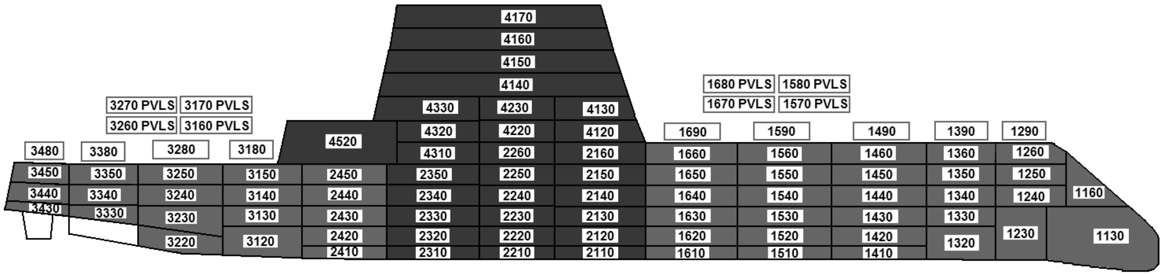

Fig. 2: Zone Breakdown Inboard Profile

secure manner while at the same time being able to access the information from any authorized computer at any time.

The flexibility provided by the IDE to the users accommodated the busy schedules of the numerous stakeholders that relied on the information to complete their reviews of the product models. Scheduling conflicts and travel costs that would have otherwise been incurred with face-to-face meetings were significantly reduced.

DDG 1000 ACQUISITION STRATEGY

One Design, Four Primes

Four prime contractors were appointed by the Navy's Program Management Office to collectively design and construct DDG-1000. However, the Detailed Design of the ship as a whole was primarily the responsibility of only two of the four contractors, specifically the two shipyards.

The Navy's Program Management Office appointed four prime contractors for the DDG 1000 acquisition. This included two shipyards and two system design and integration contractors. All four companies were responsible for the development of the Functional Design, the Detailed Design, and the Construction of different parts of the ship.

Responsibility for functional engineering of distributed systems was divided between the two shipyards, each being responsible for roughly half of the total number of systems. Likewise, the ship was geographically split into four sections, each yard being responsible for the detail design of two: one yard had the bow and stern while the other had the mid-ships section and deckhouse/hanger. The shaded construction zones shown in Figure 2 were jointly agreed upon by both shipyards in their Work-Split Memorandum of Agreement (MOA) which ultimately became contractual.

Each shipyard was responsible for the detailed design of their portion of the ship, including the placement of all systems and equipment assigned to that area whether or not that yard was functionally responsible.

Generally speaking, each zone was bounded by transverse subdivisions forward and aft, the decks directly above and below, and the shell port and starboard. The notable exceptions were the Peripheral Vertical Launching System (PVLS) Zones. The PVLS zones flanked the 1500, 1600, 3100 and 3200 column areas.

The zonal break-down allowed the Program Office to pursue a Concurrent Design-Build strategy or what is otherwise known as Integrated Process and Product Development (IPPD). With IPPD, each zone was assumed to be an independent design and therefore each zone's construction does not depend on the other zone designs to be complete before fabrication can begin. In theory, this works when inter-zone systems are considered separately. However, with DDG 1000, and perhaps shipbuilding in general, large inter-zonal systems tend to be significantly affected by the space and layout of more than a single zone and therefore the design of the zones are correlated and each zone relies, at least to some degree, on the design of the others. Support for this argument can be seen in the CAD models at the interfaces between adjacent zones.

With unlimited resources and a precisely choreographed work-flow, a design agent could potentially design the majority of the ship simultaneously, but due to personnel constraints and difficulties in logistics, it was easier to spread out the workload. The ship was divided into pieces and each piece was managed separately. This, however, increased the number of people needed to coordinate the effort which added complexity to the design process.

The design schedule was driven by the projected complexity of each zone. The shipyards had the responsibility of assessing the complexity and scheduling the zone reviews accordingly. Zone Design Reviews for each zone were held at three different points as each zone matured.

Also, the order in which the zones were developed was not always explicitly obvious. For example, the design of a zone near amidships may have been completed followed sequentially by the completion of a zone near the bow or stern. Therefore, neighboring zones matured at different rates and misalignments (i.e. piping, wireway, and structure misalignments, etc.) between zones were often prevalent at any given time during the Detailed Design phase.

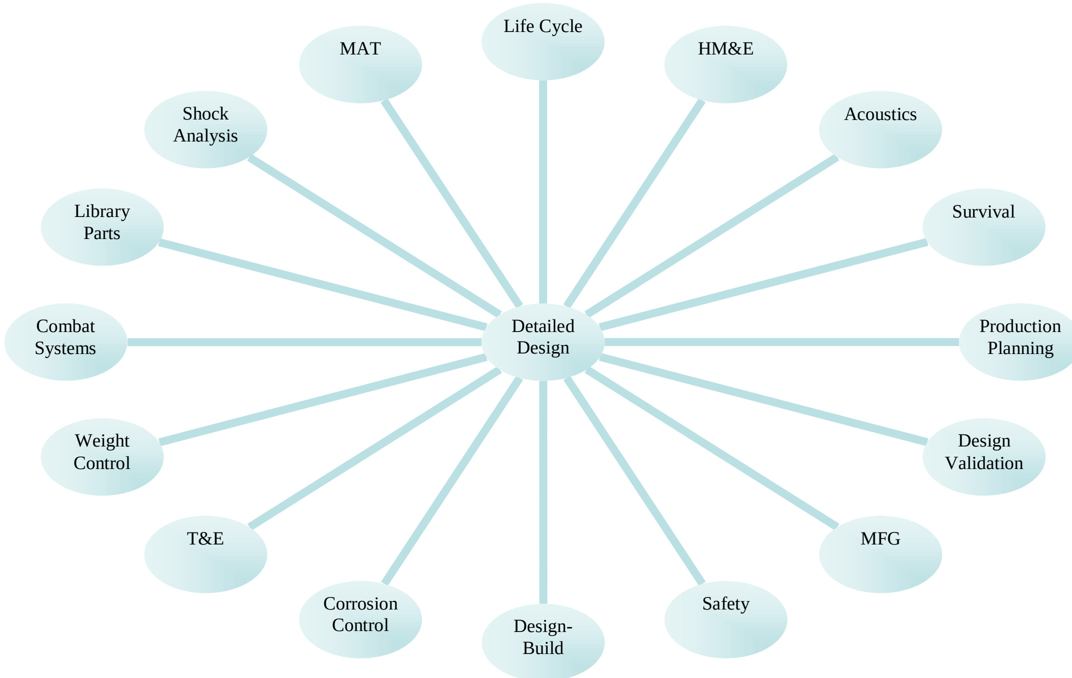

Fig. 3: Stakeholder Disciplines

All efforts were made during the review of the DDG 1000 design to minimize these impacts. The shipyards performed quality assurance and interference checks of the zones when needed. The true impact of these issues will not come to light until full-rate construction begins and blocks begin to form.

WHO WAS INVOLVED

Stakeholders

A major priority during Detailed Design was to maximize the number of stakeholder disciplines that reviewed and critiqued the designs. A diagram of all the stakeholder disciplines is shown in Fig. 3.

As far as the authors are aware, DDG 1000 has had more subject matter experts review the product models prior to construction than any previous naval ship Detailed Design effort in history. Each of the functional areas shown in Fig. 3 were represented by the shipyards and mirrored by the Navy and each was held accountable for ensuring that requirements were met. For example, the survivability engineers from the shipyards reviewed the zone designs for adequate survivability requirements as did the Navy's survivability representatives. This created a system of checks.

All of the reviewers were able to comment on discrepancies and errors with the design no matter what discipline it may have impacted. If a machinery engineer discovered that an HVAC run was hanging below the required headroom height then he or she was able and encouraged to comment on said problem.

Coordination and Leadership

To coordinate the detailed design effort the shipyards organized their work teams by zones each with a Zone Design Lead. Major Area Team (MAT) leads were responsible for the coordination of multiple zones and for the preparation for the reviews. The Navy design review team also created the position of MAT Leads. The Navy MAT Leads were responsible for the review of the major areas. Navy MAT Leads along with their shipyard counterparts facilitated the design reviews, managed minor schedule adjustments, assisted in conflict resolution and tracked performance metrics. The Shipyard MAT leads reported to their respective management chain. The Navy MAT leads reported to and worked with the Detailed Design Integration Manager (DDIM). The DDIM was responsible for the overall coordination of reviews for the entire ship. The position included the responsibility of managing the overall schedule changes, issue resolution, ensuring all stakeholders were informed and for implementing process improvements or modifications as the effort progressed. The DDIM was directly responsible to the Navy Ship Design Manager (SDM) for the Detailed Design phase.

Integrated Product Team

Integrated Product Teams (IPT) have been used on previous naval combatant designs and were originally conceived at the SECNAV level. The idea behind IPTs is to organize and group people working on a project according to their disciplines rather than grouping the team members by organization. The use of IPTs helps to eliminate many of the communication barriers that can exist on large acquisition programs. IPT efforts were linked via the IDE.

Production as a Design Stakeholder

The production planners took on a more integral part in Detailed Design with DDG 1000. With their participation, potential manufacturing difficulties were found early in the design phase to help avoid them after construction had started.

The production stakeholders were able to discuss and comment on aspects of the design that the design engineers may not have necessarily found. For instance, an engineer reviewing the structural details will review the zone for compliance to the specification and design practices while a production reviewer will review the zone to make sure there are adequate accommodations for a welder to access a densely arranged area. Issues such as build sequencing are taken into account so the production workers in the yard do not "paint themselves into a corner." A logical build sequence that can be tested in virtual space allows the planner to effectively construct the ship multiple times before ever cutting metal.

THE DESIGN REVIEW PROCESS OVERVIEW

"Designing the ship design process is a process in itself" (Keane et al. 2008).

The design review process was only a piece of the overall Ship Design Process. This process was continually updated and altered in order to accommodate the ever changing challenges of the total program acquisition.

Because of the complexity of the design and the potential for breakdowns in communications between all potential stakeholders, it was recognized early in the concept of the ship that very thorough reviews were needed. What eventually evolved through much debate and negotiations became known as the Detail Design Management Plan (DDMP). This document, though it saw multiple revisions and real time compromises, became the baseline for conducting what became know as Zone Design Reviews. The DDMP intended for each zone to go through three milestone reviews, maximizing stakeholder involvement, via the extensive use of the IDE in order to validate that the design met all requirements. The milestones would get increasingly complex in the hopes to catch design flaws of larger arrangements and equipment before smaller systems were routed and increased the density of the model and therefore the cost of fixing the flaw.

The ship consisted of a total of 94 distinct zones and each zone was expected to complete three milestone design reviews which were defined as the 50% complete, 70% complete, and 90% complete status each with their own entrance and exit criteria. The Navy was the ultimate customer of the design reviews, identified areas that were non-compliant with specifications, provided guidance and ultimately issued grades relating to the quality of the design to that point. Figure 4 shows a sample zone at 50%, 70% and 90% milestones.

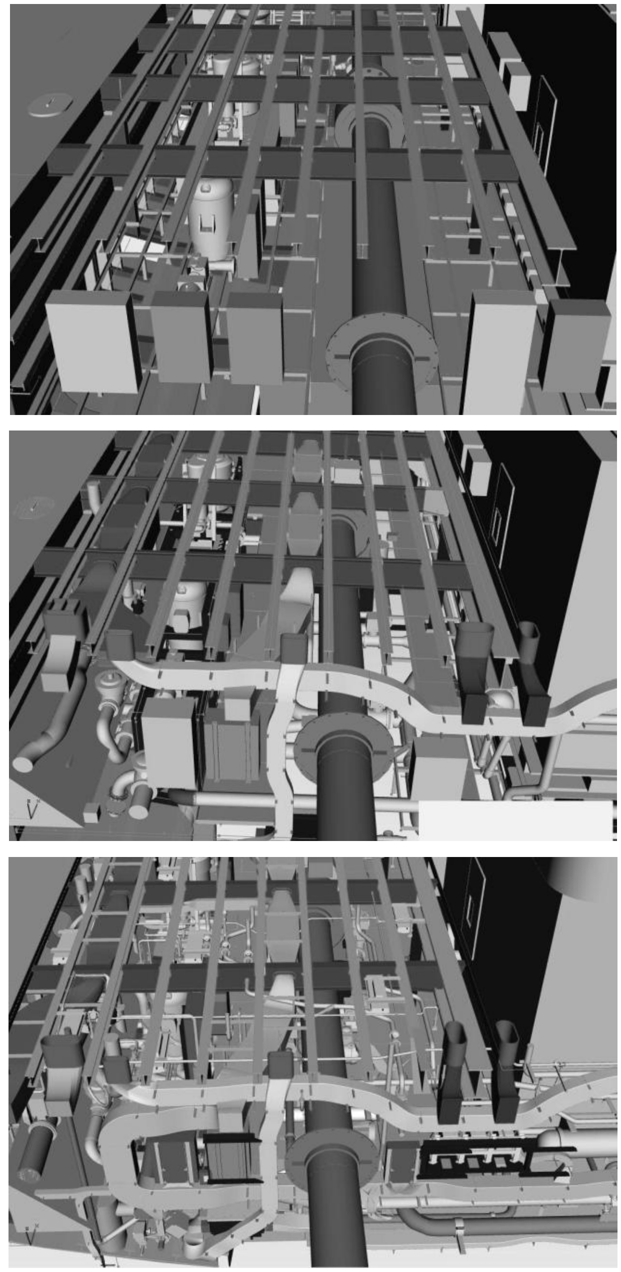

Fig. 4: (Top Down) 50%, 70%, and 90% Maturity

The Entrance Criteria for the 50% Zone Design Reviews included showing main structure, main equipment arrangements (defined as any system or component weighing over 100 lbs) and notional removal routes for major equipment in the CAD model. Navy reviewers were barred from making comments regarding piping systems and other more intricate and complex systems that were not required to be present at the 50% level but may have been present.

The Entrance Criteria for the 70% Zone Design Reviews included showing everything that was called out as Entrance Criteria at the 50% milestone plus major priority routing for distributive systems that were at least four inches in diameter. It was at the 70% review that distributive systems were first seen and the impact of smaller systems became apparent.

The Entrance Criteria for the 90% Zone Design Reviews included the Design Zone being completely outfitted and all prior review actions incorporated or identified as an open issue. The 90% maturity level was expected to contain almost everything in its correct location and orientation. Attribute information was provided to the external stakeholders, however, due to software limitations, attribute information was not easily assessable by those working outside of the CATIA environment. Attributes were defined as system specific information such as support equipment required, material type, internal components, drawing numbers, loose parts associated with the equipment, weight, center of gravity, etc.

Before each milestone was reached for a particular zone, the shipyard design team would initiate a routing slip within TeamCenter Community, which in turn would create an automated e-mail notification containing a link to the review site as well as a link to the read-ahead package contained in the IDE. This routing slip was required by the DDMP to be sent a least 7 calendar days before the milestone review date.

The Read-Ahead package contained points of contact, schedule, annotated screenshots of the zone model and, most importantly, information on the maturity of the model. Design teams used the Read-Ahead packages as a method of communicating what information was available to them to complete the design, what information was still pending, the status of change incorporation and disclosure of known issues.

After becoming familiar with the zone via the Read Ahead package, the stakeholders external to the design team were then able to virtually walk through the a light weight representation of the CAD model of that particular zone and capture issues real-time which would contain inaccuracies and problems that may have potentially impacted production of the ship. Most often, these "inaccuracies" included violations of either ABS Naval Vessel Rules or the ship's procurement specifications, although other problems such as interferences and impacts to clearance envelopes were often found as well.

Each prime contractor reviewed the other prime contractors' work as stakeholders of the overall design away from the direct view of the Navy. However, when major issues were found they were then brought to the Navy's attention during the Formal Design Review meeting.

The majority of the issues were minor problems that were easily fixed. On occasion, however, a problem would be discovered that had the potential to cause significant change to the design. It's important to keep in mind that, according to NAVSEA's SDM manual, "the design, which expends less than 5% of the total life cycle cost of the ship, largely determines the other 95% of the total ownership cost". Therefore, it is significantly cheaper to uncover flaws while the ship is still "on paper" than it is to physically rebuild parts of the ship after construction has started.

DATA FLOW

Data existed in the form of models, presentations, written documents, charts and visual issues. The IDE was used to organize and maintain this information and make it available to all stakeholders. The CAD model viewing tool called iSeries was used to review the zone models that had originally been created by the two shipyards with CATIA. iSeries provided the reviewer the capability to review a light weight version of the product model, meaning it contained only the information that was needed to perform the reviews, and it allowed team members to access the 3-D zone design renderings from anywhere there was internet access without requiring access to the design tool. Figures 5 & 6 are examples of a CATIA view and iSeries view of the same model.

One of the greatest limitations of the lighter weight models was that the attributes of each part were unavailable to the reviewers external to the shipyards unless specifically requested on a case-by-case basis. This was reported to be caused by software limitations in iSeries and would have weighed down the models significantly. The licensing cost of iSeries was a fraction of acquiring CATIA licenses and iSeries was easily and intimately linked to the IDE.

Fig. 5: CATIA Screenshot

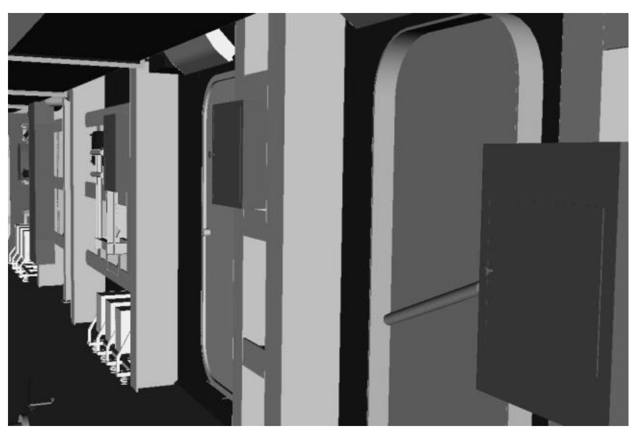

Fig. 6: iSeries Screenshot

When the design of a zone reached a milestone, the design team translated the model from CATIA to a *.jt* file and then uploaded it to the IDE. The *.jt* file was viewable using the iSeries software. The stakeholders were notified via the routing slip that the model was available and were provided a hyperlink to the model.

The Navy reviewers, using iSeries, could open the model and could do any of the following functions at their own work station at their own pace:

- Take measurements
- Create a cutting plane to view slices of the model
- Make annotations
- Draw lines and shapes to point out or highlight specific concerns
- Show/Hide equipment and their associated envelopes
- Move and rotate objects

Despite being able to work independently, reviewers preferred to work together at the Navy MAT Leads' working sessions. These sessions were typically scheduled as soon as possible after the Routing Slip was issued. The MAT Leads quickly became the experts in iSeries manipulation and assisted less proficient reviewers. The session would begin by going through the Read-Ahead package as a group. Next the model was reviewed using all the necessary capabilities. The reviewers tended to use their own computers to follow-up on details or perform a more rigorous investigation of a part or system.

When an issue was noted by a stakeholder, the iSeries/IDE interface allowed for rapid documentation. With the click of one button, an image of the model in its current configuration was taken, fields for notes, categories and description were opened, category drop down menus were available and the information was logged into a database. Each discrepancy was called a Visual Issue (VI) and the zone log of the issues became known as the Visual Issue Database (VID). Each zone had its own VID and all stakeholders were capable of seeing the issues as they were posted.

Obviously, there were sometimes duplicate issues created, because so many different people were able to create comments; however, most people were vigilant about referring back to the Visual Issue Databases in order to avoid redundant comments.

One of the most beneficial items that was logged with the Visual Issues was known as the session file. The session file locked the configuration of the model at the time the Visual Issue was taken. For instance, if the issue was noted while a cut plane was being utilized, the same cut plane and model position would be available in the session file. This proved to be useful when stakeholders and designers were looking at another's issues and trying to find its precise location. If there was any confusion as to the location of the issue noted, opening the session file would take the user to the exact spot in iSeries where the logged issue was found. The user could then manipulate the model as needed. The IDE's storage of this information saved countless man-hours that would have been wasted struggling to annotate a location or trying to describe how an issue was found (i.e. it was much easier to show an interference than to describe one).

THE FORMAL REVIEW MEETING

At the conclusion of the review period, a Formal Zone Design Review was held. The purpose of the review was to have a single meeting of all the reviewers and designers to discuss the issues and their relative impact on the overall maturity of the design zone. It also served as an opportunity to present the major issues that were found and how they would be dealt with. The formal meeting would begin by going through the Read Ahead package for the zone. This provided the shipyards with the opportunity to answer any general questions about the zone and provide any updates to the information that may have changed during the review period.

The IDE was utilized heavily for the orchestration of the Formal Zone Design Review meetings. It provided the common area for storing the material and allowed all participants an opportunity to view the same material simultaneously. The IDE used a visual conferencing application that made it possible for offsite users to view the materials being presented at the meetings. It also allowed for a participant to take control of the conference and present additional material that could be seen by all participants. If multiple computers and view-screens were available in a conference room, as was often the case, the VID could be presented on one screen while the model or a drawing could be brought up on another.

Multiple screens were a luxury not all stakeholders had the opportunity to utilize. The majority of Navy reviewers had the Product Visualization Room, (PV Room) available at the Zumwalt Collaboration Center located in Washington, DC. The PV Room contained three flat-screen plasma displays, three desktop PCs, a digital wall display, multiple network drops, and conference speakers. Fig. 7 shows the setup of the PV Room.

Fig. 7: The Product Visualization Room

At the conclusion of the meeting an overall assessment of the zone was discussed, actions were re-iterated and closing comments were solicited from all the stakeholders. Issues that were not resolved were captured and summarized to be passed up the management chain of command.

ISSUES RESOLUTION

Ideally, a VI was able to be closed between the reviewer who created the original comment and the designer responsible for the system without having to involve third parties or needing to be brought to the formal review. Obviously, not all issues could be taken care of in this manner. During the formal meetings it was typical to discuss those issues that had not reached some level of agreement between the Navy and industry. VIs that still required action after the review cycle and formal review conclusion could be handled in a number of ways.

The ideal way to handle an issue was for the reviewer and designer to communicate and call in additional personnel as needed. When this was insufficient a meeting with managers could be held to weigh each party's arguments and provide further guidance on how to bring the issue to closure.

The most difficult type of issue to resolve was a true conflict between requirements and design constraints. When requirements conflicted it was the responsibility of the contractor to point out the conflict and seek Navy clarification. Navy Technical Warrant Holders (TWH) were responsible for providing this guidance via the Program Management Office. When a requirement could not be met due to design constraints of a particular area or because of other unanticipated reasons, the contractors were responsible for seeking relief or exception to the requirement. As issues arose, designers would prepare a package to present to the Technical Warrant Holder of the requirement being violated. For instance, the Human System Integration (HSI) TWH was called upon often to discuss design constraints and HSI requirement conflicts. The ability for the design teams to present the model, the specification language, and the options that were considered to alleviate the issue proved to be extremely efficient and thorough. The TWH could verify that all measures were indeed taken to meet the specification and all available options truly did not work within the constraints. The TWH could then provide real-time acceptance or suggestions to the design team. The findings of these meetings were later formally documented for the record.

As the design review process progressed, a back-log of issues began to accumulate. VID Closure Meetings were started to focus on adjudicating the lingering issues. A lead was designated at each shipyard as the focal point for these closure meetings.

DESIGN QUALITY ASSURANCE

Getting the design right before production was a top priority for the program. Therefore, the Navy requested that reviews of the design and quality assurance checks be overseen by Navy representatives.

Management personnel in the Program Offices of both the Navy and contractors requested that metrics be developed to assess the maturity levels of the zones as they completed the milestones. Scorecards were introduced into the design process in order to maintain accountability. The scorecard reflected the stakeholder community's input toward how well a zone met the entrance and exit criteria at each of its different milestones. A green/yellow/red scheme was used to give a quick-look assessment to managers. A grade of green meant that the zone may have had minor issues and concerns, but it met its requirements. A grade of yellow was given if moving forward with the zone was considered a medium to low risk but the shipyard(s) had a plan to deal with the problems. A grade of red indicated that the zone contained a problem that may cause system failure, personnel casualty, was significantly costly, and/or contained significant omissions of equipment or ship systems.

In order to track all 94 zones' scorecards, schedules, general issues, maturity, risk and completeness, a weekly metric dashboard was developed. This dashboard was designed to fit on both sides of a single sheet of 11"x17" paper. This allowed for multiple copies to be made and distributed to interested stakeholders. As this dashboard matured, it started to be requested by increasing levels of management for its concise snapshot of the program's detailed design effort.

Weekly meetings were held to discuss the contents of the dashboard and to brief the Associate Program Manager (APM), a Navy Captain, on the maturity of the zones approaching the 90% milestone. The APM was able to decide at this meeting the risk of allowing a model to proceed to the 90% review based on the package prepared by the contractor. This additional step in the process was designed to ensure that the zone reviewers would be reviewing a model that was ready to be commented on. If a zone was found to not meet the 90% entrance criteria at this meeting the APM decided to either continue the review at risk or delay the review until the deficiency could be adequately resolved.

DIFFICULTIES FACED

As expected with any effort involving multiple stakeholders across multiple companies and organizations, there were difficulties that had to be resolved during the two and half year effort.

Design Summit

Early in the Detailed Design phase, after completing several zone design reviews, a Zone Design Summit meeting was held to discuss lessons learned from the initial Zone Reviews. Stakeholder representatives from each major organization gathered in Washington, DC with a list of common problems and recommendations for improvements. After a three day working session process improvement suggestions were sent to management for concurrence. This led to the development of an agreed upon list of stakeholder responsibilities and actions for each review. A selected summary of the resolutions follows:

- The Shipyard accountable for the zone design should enter known issues from the Read-Ahead package into the VID. Reviewers will not repeat the issue unless amplification or clarification is needed
- VI should include, whenever possible, the exact specification or requirement that was violated, the part name, approximate location, the reviewer's name and the date that the entry was made
- All MAT Leads and reviewers will sign up for IDE generated alerts when an issue has been modified to expedite response and adjudication time
- A VI should be written for each violation or discrepancy to reduce confusion caused by a single VI discussing multiple issues
- MAT Leads (both Navy and Shipyard) shall make every effort to reduce the number of duplicate VIs
- If a stakeholder has reviewed a zone and did not enter a comment, a "No Comment" VI should be entered and immediately closed for stakeholder involvement tracking
- The Read-Ahead package clearly defines the review period; comments posted after the period will not be discussed during the Formal Review but will still need to be adjudicated at another time
- There are 4 categories for adjudication that the reviewer can chose from and are now defined as: ACCEPT – The reviewer accepts the shipyard response for further work, CLOSED ─ The issue has been resolved, the reviewer is satisfied with the resolution, no further work is required, OTHER ─ The reviewer does not accept the shipyard response, the issue requires further discussion and work. REJECT – The issue as a whole has been rejected, and is not acceptable.
- A weekly meeting will be set up to discuss schedule changes between Navy and Shipyard MAT Leads. Issues and conflicts that cannot be resolved will be forwarded to management.

Schedule

The zone design review schedule was a very dynamic entity on the program. Towards the end of the program, the shipyards were briefing schedule changes three times a week to the Navy Program Manager. Unforeseen challenges in completing the design, available manpower resources and complexity of the design all contributed to the schedule changes. A simple solution to the communication issues that arose from the ever changing schedule was once again provided by the IDE. A centralized calendar was maintained on the IDE by the shipyard schedulers for real time updates to review schedules. This calendar replaced the need for the weekly MAT Lead schedule meeting and allowed reviewers changes more efficiently. The Zone Design Review calendar could be linked to most reviewers work calendars by syncing the IDE to their scheduling software.

Data Entry

There was a continuous problem through the Detailed Design effort of DDG 1000 of duplicate issues being made by the Navy reviewers. The reviewers made their best effort to avoid making duplicate issues by reviewing issues that had already been entered and familiarizing themselves with the zone via the Read Ahead packages, however, duplicate issues often still persisted. The major problem was the fact that it was extremely time consuming for the reviewers, both in the working sessions and reviewing the zones by themselves, to keep referring back to previous issues, whether they were issues made during a previous milestone review or earlier in said review.

Grading

The problem with the grading criteria during DDG 1000's Detailed Design reviews was ambiguity. The definitions of the scoring criteria were agreed upon during the Zone Design Review Summit. Unfortunately, the definitions left enough ambiguity to spark heated discussions as to the impact of a particular issue and its effect on the overall zone grade. As the zone grades became more widely dispersed, the discussion grew ever lengthier.

Formal Review

Formal Zone Design Reviews proved to be one of the most dynamic and constantly revised steps in the process. Originally, these meetings were a slow, day-long process. The read-ahead package was discussed in detail; all IDE entries were typed by a single note taker and reviewed on screen by all participants. This was a slow process that was prone to communication errors.

After many improvements, the Formal Review became streamlined down to approximately an hour. This was accomplished by assuming all participants had reviewed the Read-Ahead package and only discussing the highlights at the beginning of the meeting. Also, Navy MAT Leads sent a culled list of issues that needed a larger groups' involvement thus reducing the volume of issues. Multiple workstations were used to document decisions and adjudications real-time vice a single workstation.

If an issue could not come to a reasonable conclusion in a couple of minutes at the Formal Review, an action item was given for the interested parties to continue the discussion outside of the meeting. If a resolution could still not be resolved after this meeting had taken place, high level management was brought in.

Limitations of the IDE

Over all the IDE was an extremely valuable tool without which this process would have never succeeded. However, the IDE search feature was limited and cumbersome. To find what one was looking for without knowing the specific name or item number often meant searching through hundreds of line items on the search results. The IDE also did not have a single area to see all the individual zone VIDs simultaneously until very late in the process. Individual specifications could be searched for but there was no capability to search one document of the entire specifications for a key word.

RECOMMENDATIONS FOR FUTURE DETAILED DESIGN EFFORTS

Future ship designs will be able to leverage the lessons learned on the DDG 1000 program. The Navy, along with its industry partners, have pioneered a robust concept of detailed design reviews.

- Encourage the stakeholder to provide continuous feedback on the process to management. Some of the most time saving suggestions were also the easiest to implement
- Develop an unambiguous grading metric and procedure to reduce the conflicts and discussion that come from the lack there of. Agree to this criteria and test it thoroughly with "what if" questions.
- Data integrity will be drastically improved if comments entered by a stakeholder were locked and could not be altered by another stakeholder. This could be a simple fix to give stakeholders permission to only modify the fields they would normally be entering data into and restricting the remainder of the fields. The designers would have permission to enter responses to the comments posted by the reviewer but not alter the original comment and vice versa.
- Time stamping the comments and attachments would significantly reduce chronological confusion. Since most of the comments and responses were entered in two fields it was often confusing as to the order of the comments. DDG 1000 overcame this issue by trying to have reviewers and designers change colors of the font or put their own time stamps, but making this an automatic feature would ensure an ease of reading the VID text.
- Make working drawings available for reviewers. Working drawings of systems were not necessarily available for community to see depending on the system's maturity. This lead to disconnects between the model and the drawing which caused a VI to be written. These issues tended to be easy to resolve but could have been avoided all together.
- Develop a process for the program's detailed design effort and run several mock- reviews to work out the details. Process changes that were not fully thought out often failed after its debut. Getting new process changes communicated out to the entire stakeholder community in an understandable manner was often harder than anticipated.
- Test and re-test design software and review software compatibility.

CONCLUSION

Reviews of a ship's design have become easier to conduct and manage. The DDG-1000 Detailed Design effort has set a benchmark for the way in which the United States Navy will perform Detailed Design in the future. The DDG 1000 Program maximized stakeholder involvement by leveraging the capabilities of the IDE, centralizing information and de-centralizing model review capability. The true value of the detailed design review effort will not be known until the first ship completes its construction. An analysis of the cost of completing three dimensional reviews to the estimate cost saving of avoiding production rework would be a very valuable exercise. Detailed metrics of production issues compared to the list of Visual Issues would be one manner of conducting this analysis.

ACKNOWLEDGEMENTS

Glen and Jay would like to thank the following people for their input: Ted Poole, Mike Badal, Jason Albright, Ron Saber, Jason Minett, Jon Gordon, Carlos Luna, John Jones, Desmond "Skip" Victor, Dave Parshall, Paul Cournoyer and the General Dynamics Design Team, Tom Rainey, Alan Hinton and the Northrop Grumman Design Team, Jason Reynolds, Matt Garner, Andy Summers, George Filiopoulos, CAPT. Mike Smith, Joe Horvath, Colleen Westenberger, Jeff Merlino, Anita Kirkland, and Jeff DeMerchant.

REFERENCES

DALPIAZ, T. M., M. EMMRICH, G. MILLER, and D. MCQUILLAN. "A Human Factors Engineering 3-D Ship

Design Review." Association of Naval Engineers (ASNE) Day Symposium, Virginia Beach, VA (2005).

GAO NSIAD-90-84. "Navy Shipbuilding: Cost and Schedule Problems on the DDG-51 AEGIS Destroyer Program." 17 January 1990. Defense Technical Information Center. 21 July 2009. <http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA292582>.

GENERAL DYNAMICS ELECTRIC BOAT. "The VIRGINIA Class Submarine Program: A Case Study". Groton, CT: February 2002.

IBM. "PLM Solutions From IBM and Dassault Systemes Help Shipbuilder Pioneer Development of Next-Generation Aircraft Carrier" 22 September 2005. IBM Press Releases Webpage. 21 July 2009. <http://www-03.ibm.com/press/us/en/pressrelease/7897.wss>.

KEANE, R., H. FIREMAN, J. HOUGH, D. HELGERSON, and C. WHITCOMB. "Ready to Design a Naval Ship? – Prove It!" SNAME Annual Meeting and Expo, Houston, TX (2008).

NORTHROP GRUMMAN. CVN 21 Facts Webpage. 21 July 2009. <http://www.nn.northropgrumman.com/cvn21/facts.html>.

SCHMIDT, W., J.V. SCHAAF and R. SHIELDS, III. "Modeling and Transfer of Product Model Digital Data for the DDG 51 Class Destroyer Program." SNAME Ship Production Symposium, (1990).

ABOUT THE AUTHORS

Glen Grogan is a University of New Orleans graduate with a BS in Naval Architecture and Marine Engineering. Glen worked the DDG 1000 program for over three years including all two and half years of the Detailed Design effort as the Detailed Design Integration Manager. He is a former employee of both Alion Science and Technology and the Naval Surface Warfare Center, Carderock Division. He was recently assigned as the Design Integration Manager for In-Service CG 47 Class Cruisers.

Jay Borthen graduated from Virginia Tech with a Bachelor's Degree in Ocean Engineering and a Minor in Economics. He is currently pursuing a Master's Degree in Mathematics and Statistics at Georgetown University in Washington, DC. Jay was previously employed as a Naval Architect at Northrop Grumman Ship Systems in Ocean Springs, MS and currently holds a Naval Architect position at Alion Science and Technology in Alexandria, VA. He has spent almost three years working on the DDG 1000 program.