Fleet Maintenance & Modernization Symposium (FMMS 2017)

Build. Maintain. Modernize. Shaping the Future Fleet

San Diego, California, USA
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Ted Ingalsbe, P.E., CTO Bridgeborn Inc.
CDR Vincent Stammetti, USN, Retired

Leveraging Digital 3-D Models beyond Design and Construction for use Throughout the Ship and Component Lifecycle

ABSTRACT

This paper describes a methodology for providing a platform that includes a 3-D representation of a selected hull with the ability to interact, overlay, drill into, and visualize a wealth of data. The paper describes in detail how data related to scheduling, planning, and managing ship alterations can benefit users of the platform. The flexibility of the methodology enables engineering support and planning activities to customize the user interface specific to their area of responsibility.

INTRODUCTION

3-D Computer-Aided Design (CAD) is widely used for the design of new construction, repair, and modernization efforts for Navy Ships. However, once the ship is built or overhauls completed, these valuable 3-D assets are often archived and only occasionally re-used when new repair and modernization efforts are approved and funded.

In addition to the 3-D assets, a significant amount of data is generated to support the design, construction, and lifecycle of the ship and ship class. This includes but is not limited to schedules, maintenance records, performance data, configuration data, drawings, equipment engineering changes, and technical manuals. The data is typically in the form of databases or 2-D drawings, with limited visibility into how this data corresponds with the actual physical configuration of a ship, in either an existing or future state. Without a common platform to connect and apply data interactively from different domains and visualize its placement on a given hull, it can be difficult to make informed decisions. Too much time is spent building a mental picture of how data applies to the physical configuration on the ship and how it will be affected by change.

Applying the new construction and life cycle engineering data to existing 3-D assets would provide planners and engineering support activities a powerful tool for more efficient planning and better understanding of the data they use and manage.

Computers have changed the way we view and interact with data from multiple sources. Complex and detailed data is rolled up into information graphics resulting in "at a glance" understanding of the data. Established conventions and visuals that are commonplace today can be applied to support the lifecycle of Navy Ships by applying ship related data to 3-D Ship Models. The figures that follow are samples of common conventions applied to a Ship Information System comprised of 3-D model assets and ship related data.

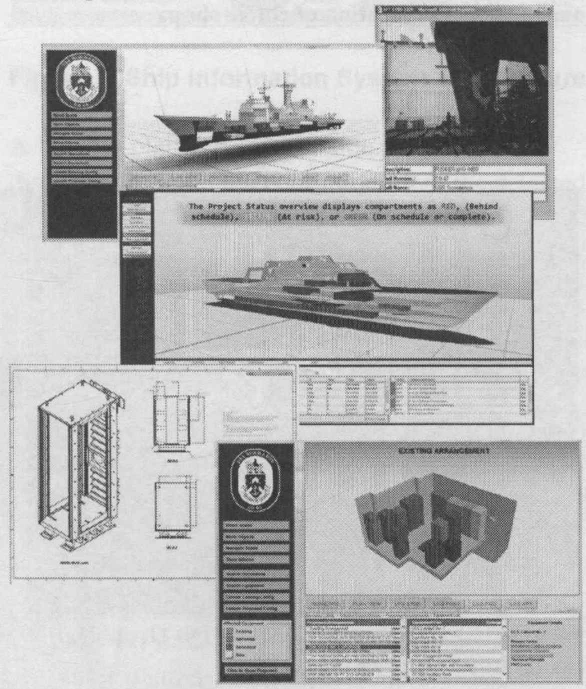

Figure 1: Ship Information System samples of information graphics.

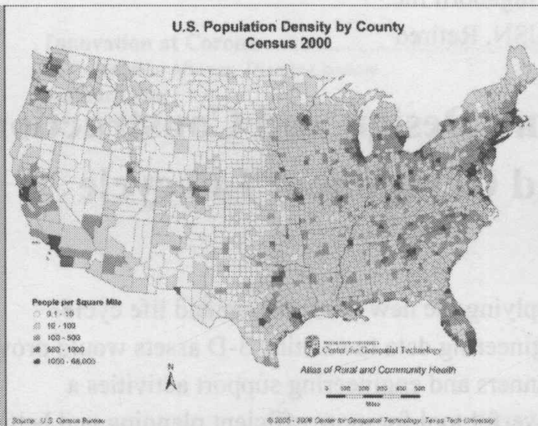

Figure 2: (COMMON CONVENTION) Colored regions to show population density

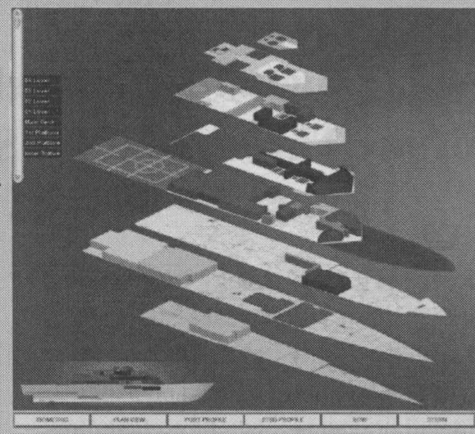

Figure 3: (APPLIED TO SHIPS) Color applied to compartments to represent manning levels

Figure 4: (COMMON CONVENTION) Graphical Icons to show the location of coffee shops

Figure 5: (APPLIED TO SHIPS) Graphical icons to show location of equipment

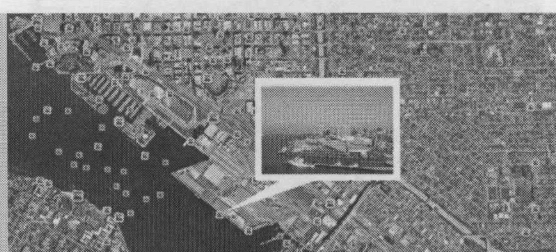

Figure 6: (COMMON CONVENTION) Graphical Icons to show where photos taken.

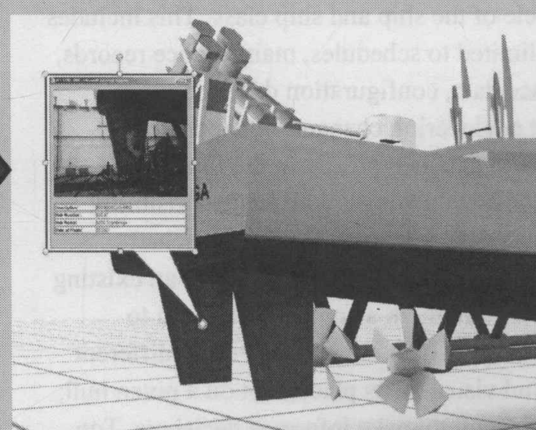

Figure 7: (APPLIED TO SHIPS) Graphical Icons to show where photos taken.

Applying these common conventions to support the lifecycle of the ship and equipment provides greater efficiency for planners and decision makers to minimize the time it takes to find the information. Presenting the information in a spatial and temporal relationship to a specific ship saves time from having to build a mental picture of where and when the data applies. All information is time based so users can see information in past, present, and future (planned) configurations.

SYSTEM ARCHTECTURE

The architecture commonly used for the established visual conventions would be similar for the Ship Information System. For example, in a mapping application the user would have a selected map, a library of data services that can be applied to the map, and widgets to allow the user to customize the display of data on the map. The Ship Information System would follow a similar pattern, substituting a selected ship hull for the map. Data standards would be developed so a variety of data can be applied as data services.

A key component of the architecture is the 3-D model library. The 3-D Model Library consists of 1) Ship Hulls 2) Compartments 3) Equipment and furnishings. The database associates 3-D models with the selected ship for a selected physical configuration. 3-D Models of the hull and compartments are re-utilized from CAD drawings used to build the ship. Equipment and furnishings are stored as a 3-D representation of details provided in Installation Control Drawings (ICD). The physical configuration will be maintained in a similar method planners use to manage weight and moment information for the ship. Weight and moment information contains the location of the equipment and furnishings within the hull and compartment.

Data services connected to established authoritative lifecycle data sources is the best method to allow the content to be shared and used in the Ship Information System. However, cultural or technical constraints to allow sharing of data are often hurdles to overcome within the DoD community. Currently many efforts are underway to enable systems to be more net-centric where data is shared among systems. A deployed Ship Information System could be a catalyst to establish more data services while exposing the value of the services and data that can be shared today. The deployment of Geospatial platforms like ESRI and Google Earth served as a catalyst for many government sources to establish data services that provided value to their communities of interest.

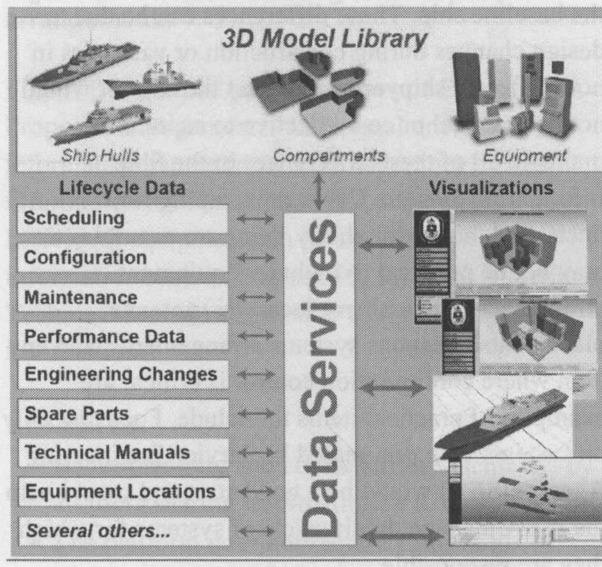

Figure 8: Ship Information System Architecture

A flexible platform and scalable architecture to dynamically build the configuration of the selected ship has several advantages over maintaining an as-built ship model in a 3-D CAD system.

- A dynamically built configuration enables information to be viewed in the past, present, and future state.
- A flexible platform based on queries to a database does not require loading the entire ship or ship section as a CAD system would.
- Data services can be designed to return filtered 3-D information where a user could select between categories such as weapons systems or radar systems. Data can also be restricted based on user role.

- Unlike the proposed solution, CAD systems or CAD viewers are not optimized to accept multiple data services and deliver content over an Intranet or Intranet.
- Costs to maintain the configuration are less expensive due to crowd sourcing the information and tracking the accountability of users providing that information.

LEVELS OF DETAIL TO CONSIDER

Each ship within a ship class is often different from the baseline ship. These differences can be due to design changes during construction or variances in how different shipyards construct the ship. It would not be practical or cost effective to capture or maintain all of these differences in the Ship Information System. Cable runs, piping runs, HVAC ducts, and most habitability items are examples that may not be practical to include. Equipment arrangements, machinery locations, antenna placements, weapons systems arrangements, and any item where configuration control is critical are examples of practical items to include. Focusing only on systems with designated In-Service Engineering Agents (ISEA) would be a good start and would help the ISEA manage the lifecycle of systems for which they are responsible.

A single hull can be defined in the following levels of detail:

Level 1: The Ship Information System is populated with a basic representation of the hull and 2-D stacked deck plans. The result gives users an understanding of the ship layout and allows data services to be overlaid in the form of place marks. Refer to Figure 7~~Figure 7~~ for a sample.

Level 2: The Ship Information System includes Level 1 detail and functionality. 3-D compartment information is added to allow coloring of compartments based on data services. Refer to Figure 3~~Figure 3~~, Figure 11~~Figure 11~~, Figure 12~~Figure 12~~, and Figure 13~~Figure 13~~ for samples.

Level 3: The Ship Information System includes Level 1 and 2 detail and functionality. Critical 3-D equipment is added to represent the general arrangements. Equipment allows color to be applied based on data services. Refer to Figure 5~~Figure 5~~ and Figure 10~~Figure 10~~ for samples.

Level 4+: Additional levels can be considered based on budgets and use cases defined by various lifecycle activities. Propulsion systems or other key machinery can be added so color could be applied to represent performance or maintenance data. Laser scanned information could be another level of detail.

USE CASE – SHIP ALTERATION DATA

Using Ship Alteration data to understand the combined effects of all Ship Alterations for a single overhaul/availability

PROBLEM

Significant time and money is spent on preparing documentation and drawings for installing SHIPALTs (Ship Alterations). Much of this time is spent trying to identify what the resulting configuration will be after the SHIPALT is installed. This involves determining the existing ship configuration and proposed configuration, as impacted by other SHIPALTs, before the SHIPALT is installed. Due to constraints ranging from limited access to current data and inadequate tools for planning and reporting, the process of determining the physical configuration carries costs, in time and money, for the Navy. This increases the cost of shipchecks and the development of Ship Installation Drawings (SIDs). Additionally, the uncertainty surrounding a given compartment's configuration risks adding a unique configuration during the installation when the shipcheck team is forced to make onsite decisions.

Why is it so difficult to determine the existing configuration when the SHIPALT is installed?

- Access to SHIPALT data is limited
- Data collection is inconsistent
- Tools and resources for effective planning and reporting are inadequate

Cumulative results of these problems

- Redundant data is collected by multiple shipcheck teams.
- Shipchecks take longer because teams are not adequately prepared.
- Information resulting from shipchecks is not passed on to other planning activities in a timely fashion.
- Other planning activities waste time guessing at the proposed ship-specific configuration often requiring corrective action later in the installation phase.
- No individual or shipcheck team accountability for information gathered or reports generated because this data is not tracked.

These problems manifest themselves in wasted time and unnecessary spending on labor and man-hours required to do work.

SOLUTION

Information contained in the Ship Alterations Records (SARs) can be applied to the 3-D model of the ship for a greater understanding of the changes occurring for an overhaul or availability. Shipcheck information such as photos, notes, drawings, and diagrams can be shared among other planning teams using the common platform. Accountability of information uploaded can be tracked by user.

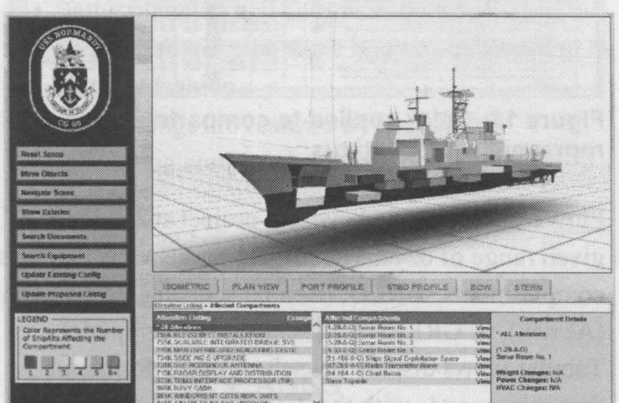

Figure 9: Cumulative view of affected compartments for an overhaul or availability

Figure 9~~Figure 9~~ shows compartments affected by all SHIPALTs for a given overhaul or availability. Hotter colors such as red indicate several SHIPALTs affect the compartment.

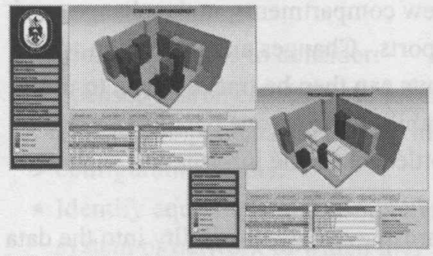

Figure 10: Views of Existing and Proposed arrangements

Figure 10~~Figure 10~~ provides views of Existing and Proposed arrangements. Additional drill down information can be associated with models to provide information for Power and HVAC impacts. Individual equipment can be associated with information such as Engineering Changes, drawings, Technical Manuals, and other equipment specific information.

BENEFITS

- Better planning and coordination is achieved by all users sharing information in a timely fashion.
- The platform does not require CAD skills in order to generate the majority of the information. Any user capable of taking measurements and recording them in the database via an input form can create 3-D arrangements. These skills are already required to record weight and moment data.
- Using the Ship Information System does not require new skills. It standardizes the process, manages data more efficiently, and generates reports from work that is currently done using lifecycle data.
- Users of the tool get a complete picture of the current configuration without having to assemble the information from drawings they may or may not have. The result is better planning, fewer surprises during shipchecks, and reduced time and effort required for the shipcheck.
- The database can be accessed and updated by

anyone from any location. That means shipcheck teams/contractors, government representatives, and installation teams can use the web to access the data, view compartments, make changes and generate reports. Changes and updates to compartments can then be tracked back to users for accountability and no one person or group acts as a bottleneck in the information exchange and update process.

- Planning yards have better visibility into the data and efforts managed by other lifecycle supporting activities.

USE CASE – SCHEDULING INFORMATION

Applying Microsoft Project Scheduling data to the Ship Information System to better understand and manage a ship overhaul/availability

PROBLEM

Integrated Master Schedules can have thousands of tasks included in them making it difficult to understand or communicate overall progress due to the size of the schedule. It is also difficult to understand where various tasks are being accomplished with regard to their location on the ship. While the schedule often includes the names of compartments it forces the user to build the mental picture of the ship and where tasks are performed.

SOLUTION

Applying data from the schedule to the physical ship can greatly enhance the understanding and execution of the project schedule. Integrated Master Schedules are commonly built using Microsoft Project. The output of Microsoft Project can either be uploaded to the Ship Information System or connected directly if using the server based version of Microsoft Project. Tasks would be associated with the physical ship by a compartment designation. Once uploaded, several views can be established to help understand and manage the schedule more efficiently. Each view can be filtered by range of days, task type, vendor, or any other element contained in the schedule.

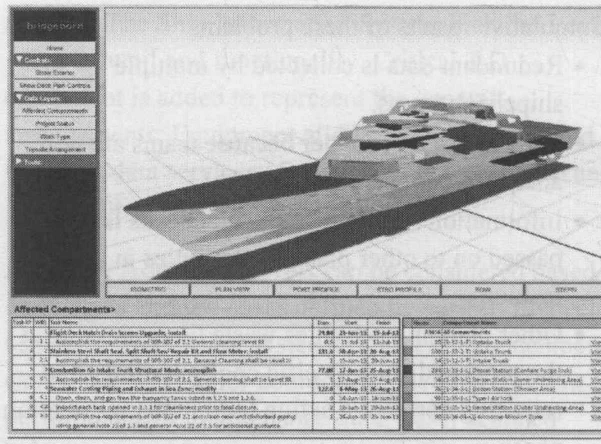

Figure 11: Color applied to compartments to represent labor hours assigned

Figure 11~~Figure 11~~ shows the cumulative assignment of labor hours for a given range of days. The darker the BLUE the greater number of hours allocated to it. Tabular views display content normally viewed in the project schedule with the ability to filter and drill down into the details.

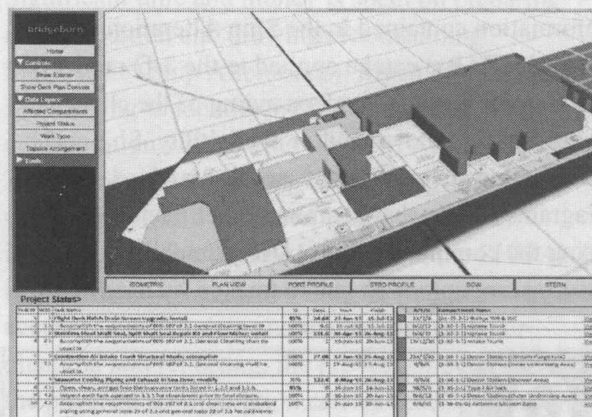

Figure 12: Color applied to compartments to represent project status

Figure 12~~Figure 12~~ shows the project status for a given range of days. The Project Status view displays compartments as RED, (Behind schedule), YELLOW (At risk), or GREEN (On schedule or complete). Tabular views display the scheduling information that corresponds with the data displayed in the 3-D visual.

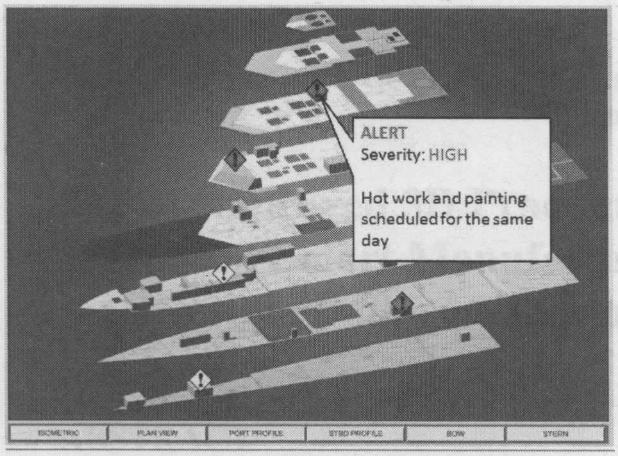

Figure 13: Icons to represent scheduling conflicts, alerts, and risks

Figure 13~~Figure 13~~ shows how conflicts, alerts, or risks can be displayed. Whether it's during the development or revisions of a schedule, predefined business rules alert the planner to the existence of a problem. An example of a conflict would be hot work scheduled near the same location as painting. Due to the fast pace of an overhaul it is difficult to reconcile similar conflicts when a change in the schedule is made. Often these conflicts are realized on the day of execution when workers show up in the same compartment. Identifying the conflicts when there is a schedule change avoids the cost and time it takes to resolve it on site.

BENEFITS

- Better planning and coordination is achieved by all users sharing the same body of information in a timely fashion.
- Cost savings are realized by identifying scheduling conflicts before an onsite conflict occurs.
- Lengthy and complex schedules are easier to understand and track progress.

OTHER USE CASES

Lifecycle management of the ship and systems requires significant knowledge of the physical ship in its current and future configurations. Many disconnected activities produce data to support the lifecycle. Enabling an open system platform with common data standards allows stove-piped information to be compared and shared among the supporting activities.

Additional use cases to consider:

- Focused search capability to locate equipment, system components, or other critical configuration items.
- Identify equipment and components by the system or network to which they belong.
- Conduct cross-hull analysis to identify engineering changes or software changes.
- Conduct cross-hull analysis to compare arrangement variations and identify where unique configurations can be reduced.
- Operational alerts to indicate when routine maintenance is required.
- System views to indicate status or readiness.
- Display of performance data on propulsion or other key systems. Data can be displayed on key components by color and time.
- Overlay Light Imaging, Detection, And Ranging (LiDAR) information to compare database arrangements with the actual physical arrangements.

CONCLUSION

This paper discussed examples of how 3-D ship assets can enhance the value of lifecycle data. Establishing an open architecture platform for use by all support activities enables many other possibilities to apply lifecycle data to 3-D assets. Utilizing crowd sourcing to develop and maintain the data saves the Navy countless hours in managing the information and enables improved configuration control. Potential benefits include:

- Quicker understanding of data that contains spatial references using 3-D visual metaphors.
- Identification and reduction of conflicts and risks within integrated master schedules prior to and during construction or alterations.
- Minimize "configuration creep" by showing and accessing configurations in the present and future across multiple hulls.

- Displaying maintenance alerts to identify when and where key equipment or systems require attention.
- Resonate with younger generations of workers that now expect advanced 3-D visualizations.
- More efficient In-Service Engineering management with better access and understanding of ship related data.
- Any ship related data with spatial references can be added to the Ship Information System. The Ship Information System uses an open architecture approach to easily incorporate new data sources into the interface.
- The Ship Information System saves time by showing visually how and where systems are affected by change, eliminating the need for the planner to build this picture mentally.

Ted Ingalsbe, P.E., is the CTO and co-founder of Bridgeborn Inc. He oversees product development across Bridgeborn's Federal and Commercial business units as well as the engineering functions of Bridgeworks™ 3-D visualization technology.

CDR Vincent Stammetti, USN, Retired is a Vice President at Alion Science and Technology. He supports Alion's programs and business pursuits.

Tom Donovan, CAPT, USN (Ret.), Erin Bradner, Ph.D., Ulf Lindhe, M.Sc. Naval Architecture
Autodesk, Inc.

Use of Improved 3D Product Model Outputs Integrated with Advanced Smart Manufacturing Concepts and Technologies to Design, Build, Maintain, and Modernize the Fleet

ABSTRACT

The ability to generate advanced, intricate 3D product models has evolved significantly over the past decades. This has been in response to increasing demands for improved 3D models that result in better-performing components, often at equal or less cost. But while performance demands have increased, the number of design options available to meet these demands has not increased to any meaningful degree.

Breakthroughs in the additive manufacturing technologies used to fabricate components provide unprecedented opportunities to meet increased performance demands. However, the cost of these technologies currently restricts the use of additive manufacturing in commercial and military enterprises.

This paper will address these challenges, and highlight breakthroughs in design and additive manufacturing simulation technologies. This paper will also present the concept of "smart manufacturing" and will outline how the Navy can combine it with technology advances, integrated within a seamless process, to better design/build, modernize, and maintain the fleet in the future.

INTRODUCTION

For decades, traditional product engineering design and manufacturing was based on 2D paper drawings, milling, and casting approaches. In 1983, a design technology breakthrough was made that enabled computer aided design (CAD) technology to move from mainframe computers to desktop computers. This breakthrough allowed engineers to move the design process to their personal computers to dramatically improve collaboration, flexibility, and productivity. Further design technology advancements led to the development of 3D product models infused with engineering characteristics, features, and parameters. With further advancements, simulation technologies were incorporated to evaluate these 3D product models' performance, and to refine and improve design outcomes.

Despite these advances, current design methodology still begins with an engineer or team of engineers whose design concepts are informed by their education and years of experience. Additionally, the design output and analysis iteration process—though it is aided by CAD and simulation technologies—is still very time-consuming, tying up valuable time and limiting engineers' productivity and the number of design options that can be produced and analyzed.

The advent of generative design technologies fundamentally changes how engineers of tomorrow will tackle design challenges. Generative design offers the opportunity to redesign legacy components to improve their performance. This approach can also be used to rethink how individual components are integrated at a systems level for improved performance.

Preceding the recent development of generative design technology, significant advances have been made in traditional manufacturing technologies, including multi-axis milling machines and computer aided manufacturing (CAM) using computer numeric coding (CNC) to drive these machines. Beginning more than 30 years ago, 3D printing—and subsequently the term additive manufacturing (AM)—appeared in the manufacturing lexicon. Today, advances in AM machines, software, and materials have increased exponentially.

With these dramatic changes in design and manufacturing technologies, it is essential that today's engineers understand what each technology offers. Just as important is an understanding of the optimal method for integrating these technologies to markedly improve how tomorrow's fleet is designed, built, maintained, and modernized.

GENERATIVE DESIGN

Generative design is the practice of "recruiting" algorithms to synthesize a design solution using design goals and constraints as inputs. The generative design approach to design emerged from recent advancements in artificial intelligence (AI) and the engineering simulation technology that is enabling today's software to play an active, participatory role in the synthesis of design. These advances enable designers to craft a definition of a design problem through goals and constraints, which is then used to synthesize alternative design solutions that meet the objectives. Designers can explore trade-offs between many alternative approaches and select their optimal design solution.

Through the systematic application of generative design software tools, engineers can generate and analyze the performance of very large sets—thousands to tens of thousands—of different structural configurations to solve a single design problem. Generative design is broken into the Inspire phase, the Generate phase, and the Explore phase, which then feeds into fabrication.

This approach to design not only shortens the latency between digital design, physical prototype, and validation, but also lends itself to the discovery of unexpected high-performing designs that would not have otherwise been considered through traditional methods.

As shown in Figure 1, the generative design workflow involves three phases: Inspire (Define), Generate, and Explore (Select). Once the three phases of the process are completed and a final design product model is selected, the next step is to move to fabrication, where the technologies and processes associated with additive manufacturing and smart manufacturing are applied to produce a final product.

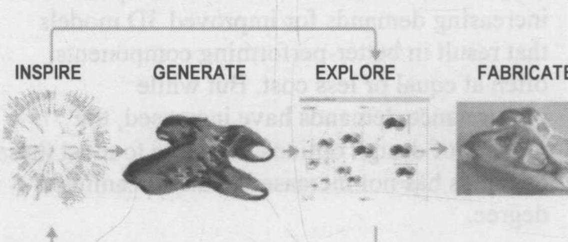

Figure 1: Generative Design Workflow

Traditionally, a designer or engineer begins the Inspire phase of the process by considering the numerous goals and constraints of the problem. The process begins with the application of the brain's limited computing power combined with the individual's training and experience. During the inspiration phase, the individual works to solve as many constraints as possible, as shown in the left segment of Figure 2. Given the limited computational capacity of the human mind, only a limited subset of constraints can be considered simultaneously, as shown in the right segment of Figure 2.

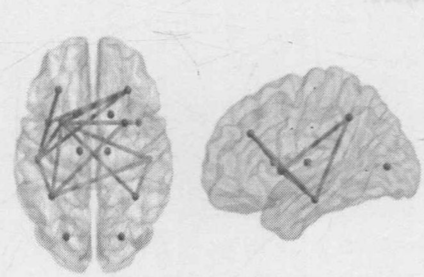

Figure 2: Cognitive Approach to Design

Once the inspiration phase is complete, design ideas that are formed in the designer's imagination are translated into cubes and spheres in 3D CAD, as shown in Figure 3. However, the linear, limited design inspiration process cannot keep pace with the design demands of the future as systems become much more complex. The ideal solution would be that each designer has a super computer at his or her disposal.

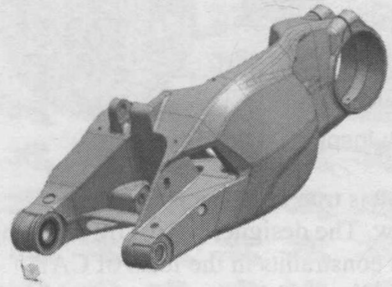

Figure 3: 3D CAD Design Drawing

Many in the industry believe that in the future, the role of the designer and engineer in the Inspire phase will fundamentally change as they use advanced computing power to exponentially improve the number and quality of design outputs. Basic outcomes from this situation will include, at a minimum, the ability to: 1) mine for promising design patterns from existing designs out in the world; 2) run trade-off analyses on dozens of objectives simultaneously; and 3) generate thousands of solutions algorithmically.

A specific notional use case that demonstrates the potential of generative design is the motorcycle swingarm highlighted in red in Figure 4. The swingarm is a structural part that holds the back wheel to the engine and shock mount.

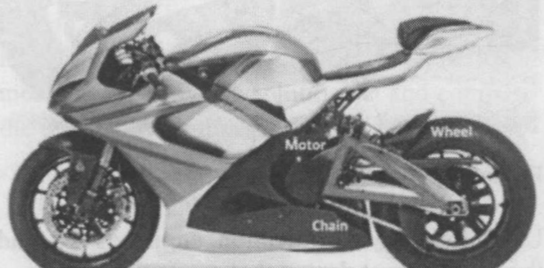

Figure 4: Notional Design Problem: Motorcycle Swingarm

During the inspiration phase, a designer can produce only a limited number of design options. As the designer transcribes motorcycle swingarm solutions into CAD, the outcome from an ideal numeric standpoint would most likely resemble the outputs shown in Figure 5. Following a subsequent analysis process using CAD and simulation tools, the net of those efforts would result in one or two suitable options, as depicted in the red-bracketed images in Figure 5.

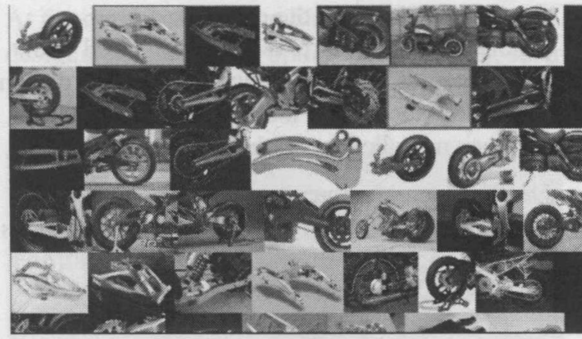

Figure 5: Design Outputs Using Traditional Design

Intuitively a designer knows there are multiple, and potentially much better, solutions. These exponential outcomes are depicted in Figure 6.

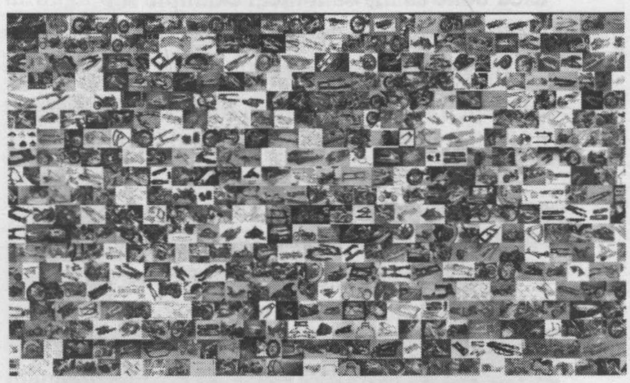

Figure 6: Generate Phase

The challenge for the designer is that the optimum solution space is too expansive for one designer to mentally search without decades of experience and without the benefit of almost unlimited time. Adding to the design complexity and uncertainty are several variables, including the effects of: 1) swapping material; 2) increased performance requirements; and 3) different manufacturing methods.

Design permutations and trade-offs can boggle even the most experienced designer's mind. Given the increasing complexity of today's systems and the challenges facing designers and engineers to design, build, modernize, and maintain these systems, new technologies must be applied to address these challenges.

From a design perspective, traditional CAD tools have reached their limit. These tools lack the capacity to solve the complex design problems of the future, even when paired with design genius and experience. Generative design is the "key tool in the tool kit" that will address the design challenges of the future.

Designers and engineers are looking outside the CAD world and posing the question: "How does nature design?" Millions of years of evolution have led to progressive and transformative improvement to biological structures. In nature, the failure to improve and adapt leads to extinction. In most mammals, bones grow to reinforce weight-bearing surfaces, as shown in Figure 7. This concept, called "Nature's Form Follows Forces" was articulated in 1917 by the Scottish biologist Sir D'Arcy Thompson, who used bone as his canonical example for morphogenesis.

As illustrated in Figure 7, morphogenesis is the concept that the form of an object is a diagram of its forces. The algorithms used in the development of generative design use this concept of morphogenesis. Thus, not surprisingly, many of the design outputs from generative design strongly reflect biological structures.

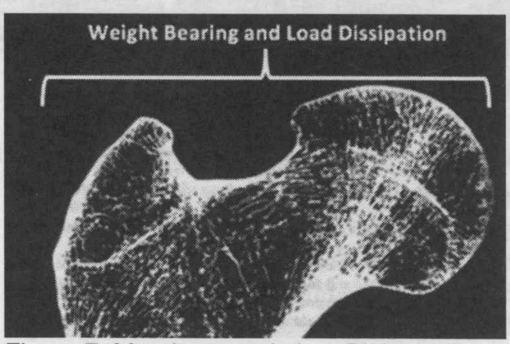

Figure 7: Morphogenesis in a Biological Structure

When a designer or engineer is approaching any design problem (as shown in Figure 8), they begin by considering the goals and constraints of the problem.

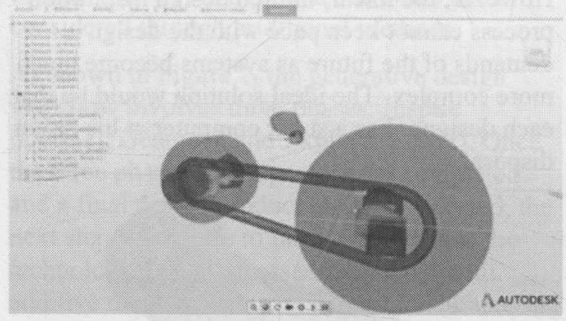

Figure 8: Inspire/Design Phase

The same is true of a generative design workflow. The designer begins by inputting physical constraints in the form of CAD representations of the interfaces to which the generative design algorithm will 'grow' during the synthesis process. The designer also specifies obstacles that constitute a no-grow zone for the geometry to avoid during synthesis.

As depicted in Figure 9, the designer can then specify loads for the algorithm to solve against. During the Generate phase of the workflow, the designer specifies what synthesis approaches the system should pursue. One approach is topology optimization, which is a mathematical approach that optimizes material layout within a given design space, for a given set of loads and boundary conditions to meet a prescribed set of performance targets.

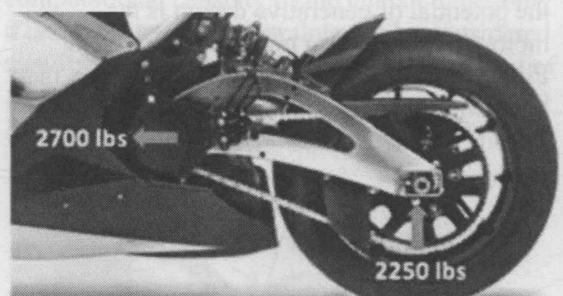

Figure 9: Specifying Loads Phase

Using topology optimization, engineers can find the best concept design that meets the design requirements. The other approach is a