

# COMPLEX DESIGN PROCESS MODELLING – US NAVY CASE STUDY

This case study provides details of how Plexus Planning was used by the US Navy to capture the highly complex processes of ship design, using techniques that are applicable in all industries.

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## SHIP DESIGN PROCESS MODELING: CAPTURING A HIGHLY COMPLEX PROCESS

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### ABSTRACT

At the 10th DSM Conference, a team of ship designers working to document the naval ship design process was introduced to DSM methods. The design of a naval surface combatant ship is an extreme example of complexity management. DSM was applied to attempt to capture of expertise from the technical community, through a series of workshops. A custom-built, integrated database approach was planned to document the results. Progress was reported at the 11th DSM Conference. Subsequently our team discovered COTS software (Plexus) that not only served the database function and provided multiple views of process data, but also provided a dynamic modeling/viewing user interface that proved more intuitive to ship design practitioners. This paper describes our progress, including the workshop process, framing principles (semantic rules and conventions) that proved helpful, our use of Plexus, the model we have created, and our intended applications for that model.

*Keywords: ship design, Navy, Plexus, COTS, DSM, knowledge capture*

## 1 INTRODUCTION

This paper is to update the DSM Community with regard to progress on the US Navy's ship design process modeling efforts since the 11<sup>th</sup> DSM Conference. The background of the Navy's ship design process modeling efforts will be reviewed, with references to prior DSM presentations and other recent publications. This includes the description of six Ship Design Process Workshops that have been conducted and the challenges of capturing and understanding knowledge this domain. Initially, our effort embarked on building a custom database, to store this knowledge, but eventually we found another solution, via commercial-off-the-shelf software which will be described here. Use of this software has allowed us to formulate a generic process model of value for four distinct applications.

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## **2 BACKGROUND**

Our efforts began with the need for evaluation of the software tools and processes used in ship design, and a need to understand the return on investments in these tools, to prioritize investments in them (the key objective of the Design Tools Roadmap Project, reported in our paper at DSM'09 [1]). Quickly it was discovered that this need could not be satisfied without a design process model to provide context. Simply stated, there was little formal documentation of Navy knowledge of the ship design process (and certainly none in a format that would permit quantitative analysis of alternative processes), and therefore the value of tools within this process simply could not be assessed. Note that our purpose here is distinct from systems engineering, integration and validation processes, requirements definition or architectural design. The goal is to capture and understand poorly documented existing processes in the first instance, not to engineer new processes.

To face this challenge, our team drew on the expertise from the Navy Technical Warrant Holder community in order to build the model, taking advantage of existing Design Process Workshops, sponsored by NAVSEA, the Office of Naval Research (ONR) and the CREATE Program of the Office of the Secretary of Defence (OSD). The Workshops engaged a broad spectrum of the ship design community. Among the Workshop attendees were experts in Machinery Design, Integrated Topside Design, and Mission Systems.

Having a way to extract a high-quality process model description from this community of seasoned experts without existing documentation presented two main challenges

- There was a need to carefully store the process knowledge that we captured
- There was a need for a productive, well-regulated process by which the knowledge would be captured.

Initially, we began addressing the first challenge (how to store the model) by designing a database in which to store dependency knowledge. However, we discovered a commercial off the shelf tool (Plexus, discussed below), which provided a more than adequate data model, stored in sophisticated database, accessible through collaborative, real-time networked clients.

To address the second challenge (a methodology for capturing the knowledge), we initially considered using the DSM itself as a knowledge capture tool. However, while DSM is a compact presentation of the dependencies between tasks in a process, and affords analysis and manipulation opportunities once the knowledge is captured, “filling in” DSMs (for instance, in Excel spreadsheets and similar tools) was not found to be an intuitive process for most ship design practitioners. Some studies have been conducted in the relative merits of users attempting to understand connectivity models like DSMs in matrices versus node-link representations (see [2] and its references), and these studies indicate some preferences for each representation in certain tasks. However, the process of knowledge capture, from multiple real-world experts, in workshop settings, using sophisticated, interactive software tools for matrix and network creation, manipulation, and visualization, is a relatively unexamined topic.

In our real-world experience of this sort, we found a productive means of capturing knowledge via Plexus, a commercial off the shelf tool that affords collaborative construction of boxes-and-arrows diagrams, that can then be visualized as DSMs, and then subjected to several types of analysis, including cycle identification, partitioning, tearing, automatic optimized scheduling, critical path, and stochastic analysis. Plexus was found to be a versatile tool and powerful methodology with outstanding ability to elicit and represent complex networks of activities and dependencies with alternative or cyclic logic. PLEXUS supports activity grouping in multiple hierarchies and significantly facilitates sequencing, scheduling and other trade-off analysis for multiple objectives.

The construction of our process model in Plexus was driven by a “product model” approach to process model development. That is, the elements of the ship itself, divided into systems, framed our methodology of knowledge capture. Our product model approach provides the same information in different ways to suit the user; this builds on the classic educational theory of multiple intelligences and is a powerful aspect of our current approach.

## **3 FRAMING PRINCIPLES FOR THE MODEL**

The complexity of the ship design process makes development of a ship design process model challenging. It quickly becomes apparent that the experts from which we are capturing knowledge

bring a localized frame of reference (if they are subject matter experts) or a particularized frame of reference (if they have been involved in design integration for a particular ship design in the past). They often use different terms to describe the same thing and/or the same term to describe different things. It is easy to end up with a stack of “expert views” in English that are impossible to comprehend or to collate into a common model that can be understood. Therefore, it is necessary to have a model framework that is robust enough to receive the knowledge captured from these diverse perspectives, and a pre-arranged method to collate their answers into a model which can be manipulated and analyzed to yield answers to the fundamental questions. An important aspect of this framework is the realization that, during design, there are two major vectors of activity – **Physical Integration and Requirements Satisfaction**:

- **Physical Integration** is achieved by making sure all the definition products are consistent (e.g., the general arrangement aligns with the hull form, the systems support the arrangement of spaces and components, etc). The emphasis is on definition activities and definition-to-definition transactions. The quantity of data values in these transactions is very large.
- **Requirement Satisfaction** is achieved by evaluation activities to generate cost, performance, schedule and risk estimates that are compared with requirements. Some evaluation activities require inputs from multiple definition activities. Other evaluation activities require input from only a single definition activity. Some evaluation activities require inputs from other evaluation activities, but the quantity of data value in these transactions is small. The emphasis is on evaluation activities and definition-to-evaluation transactions, where the quantity of data values to be transferred is very large.

Early in the preliminary phase, the design team is willing to be fast and loose regarding the Physical Integration vector as many concepts are tried and discarded. Near the end of the preliminary phase and certainly in the contract phase, there is more emphasis on simultaneous satisfaction of the Physical Integration and Requirements Satisfaction vectors. In detail and transition design phases, emphasis is mostly on Physical Integration at a high level of detail. Total-ship Requirement Satisfaction is presumed or occasionally checked. Detail Requirement Satisfaction (pipe flow rate, etc) is the emphasis of evaluation activities.

This “two vector” frame provided much of the insight into modeling principles that we emphasized in our workshops, and used as controls on the construction of the model. These principles were focused on discipline in the model semantics, and using a regulated vocabulary. In our boxes-and-arrows modeling exercise, we emphasized that boxes are *verb phrases*: activities that are done to components of the product model. Arrows are those artifacts. Plexus includes the ability to add names and descriptions to both boxes (DSM rows/columns), as well as arrows (dependency marks in a DSM), have names and descriptions. Given this, our regulated vocabulary consisted of:

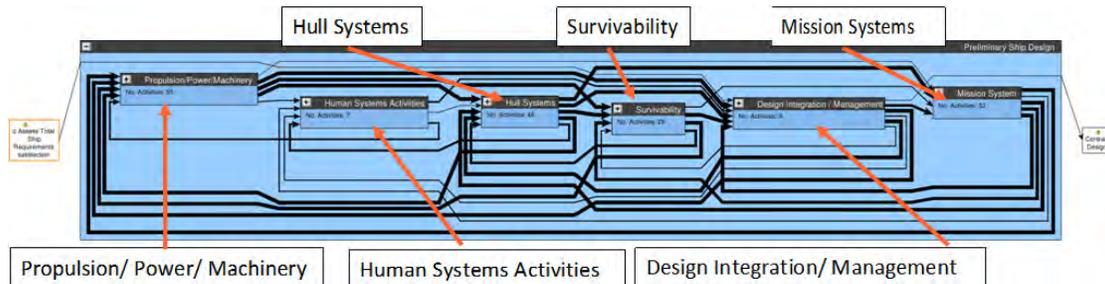
**Verbs:** in constructing the verb phrases that name activities (boxes, or DSM rows), we wanted consistency of meaning, and a small set of possible verbs, with clear definitions, to develop a model with consistent semantics. Using the “two vector” frame discussed above, and after some iteration, the following set of four verbs were decided upon, and used across all the multi-disciplinary elements of the model, to good effect:

- **Review/Set:** considering requirements and selecting margins and approach
- **Define**
- **Assess:** considering and evaluating results
- **Report or Circulate**

**Levels of Detail (Adjectives):** The ship design process is characterized by progressive development of definition detail over the course of several years. To represent this consistently, our team developed a “shorthand” to allow quick but explicit reference to the level of definition resulting from any particular “definition” activity. This is also useful for quickly characterizing the extent of definition input information necessary before certain applications can be executed. Thus, we adopted a careful vocabulary on levels of detail. The vocabulary varied across three levels of ship design (Shape, Structure, and Systems), and in each provided appropriate levels of detail, extracted from design experience (e.g., Parametric, 3/2.5D Surfaces/Arrangements/Reservations, Manufacturing Detail, Maintenance Detail, etc.). Complete discussion is not included here for the sake of brevity.

**Nouns:** the activities of our model operate on parts of the ultimate product of Ship Design. It is important to note that not only the boxes of our model (activities) have names and descriptions, but so

do the arrows. Moreover, these parts and information artifacts are organized in a product/system focused Work Breakdown Structure (WBS). This not only helps organize the work of knowledge capture (such that particular groups can work separately on particular aspects of the model) it also provides a means of collapsing and focusing attention on parts of the model for analysis and understanding. A collapsed version of the Preliminary Design Portion of the model, showing the high-level WBS elements that were used to form collaborative groups for knowledge capture, is shown in Figure 1.

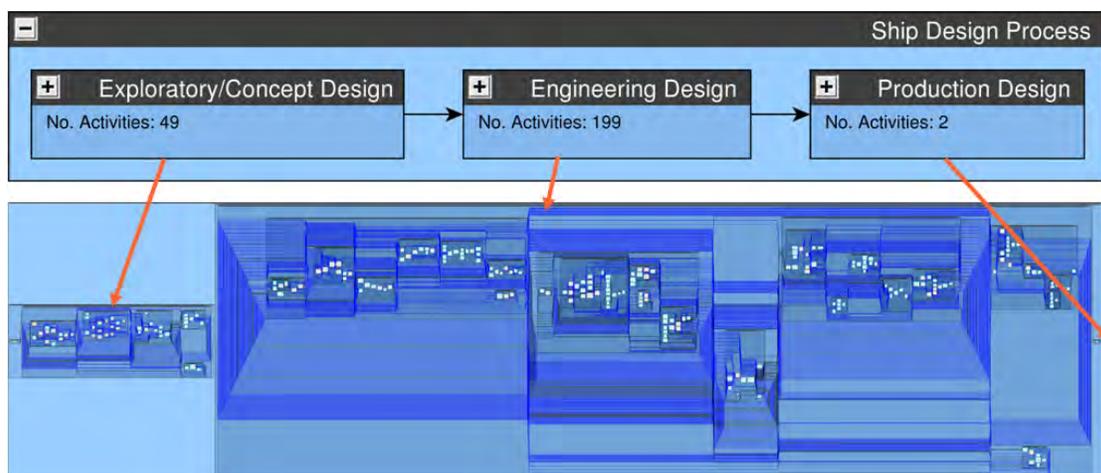


**Figure 1: The Preliminary Design portion of the Ship Design Process Model, showing the high-level WBS elements used to organize the model and the knowledge capture process. The boxes are WBS elements “collapsed” in Plexus, with the thickness of connecting arrows indicated the number of connections between activities within those boxes.**

**Resources (More Nouns):** The model includes not only Activities and their products (at various levels of detail), all organized in a WBS, but it includes the specifications of the time and Resources required to perform those activities. Thus, we also created a standard lexicon of resources, including:

The regulated vocabulary provided a frame for knowledge capture in our workshops, which were broken down into 3-5 groups based on the highest level of our WBS. These groups worked separately, but simultaneously, on a common database that captured the overall model, through a networked set of 5-10 Plexus clients. Each group consisted of around 20 participants. Plexus facilitated easy import (via comma separated value files) of knowledge we had captured in our workshops before we began using the tool, and some of this knowledge “seeded” further model developing in the workshops.

A collapsed version of the model, along with the expansion to show all the connectivity, is shown in Figure 2. While this static figure may be difficult to read, Plexus allows for sophisticated interactive zooming, panning, collapsing, expanding, focusing, and path following that facilitate a user’s ability to create, visualize, organize, and analyze models of this sort.



**Figure 2: The Ship Design Process Model, in collapsed and expanded forms.**

#### 4 INTENDED APPLICATIONS

Since the inception of our project, we have identified four main applications of our ship design process model:

- Identifying specific gaps and weaknesses in our ship design capability, particularly with respect to design tools.
- Providing a means of estimating the value (ROI) of specific design tool (activity improvement) and interoperability (transaction improvement) investments.
- Providing a flexible tool for particular ship design project planning that will facilitate identification of critical paths and optimum sequencing of engineering efforts. This could be particularly valuable for ships with mission requirements, configurations, or technological challenges that are different from traditional warships.
- Providing a core reference and directory for Navy ship design process documentation to serve as a training aide for next-generation ship designers.

We intend to build a center of excellence or competency that can become proficient with the tools, build a reference library, maintain configuration control, and be available to assist projects as needed. The objective is to make the service valuable and desired and respond to the “pull” of the ship design manager community, rather than dictate that the model be used. We are nearing the point of using the model in several “real world” surface combatant design projects.

In support of these objects, Plexus offers capabilities that our team particularly value: its versatility as a tool, its powerful methodology, and its outstanding ability to elicit and represent complex networks of activities and dependencies with alternative or cyclic logic. Plexus supports activity grouping in multiple hierarchies and significantly facilitates sequencing, scheduling and other trade-off analyses for multiple objectives. Two particular capabilities are worth particularly noting:

#### **4.1 Focusing, Filtering, and Multi-Domain Modeling**

To accomplish many of the goals we have for the model, we need to be able to examine and analyze the details we have, and be able to expand that detail as necessary. We also need to add detail in multiple domains: while WBS provides an excellent domain for a product driven process modeling procedure, we also need to tie activities to location, organizational responsibilities, etc. We also need to examine the project by filtering through these multiple domains: asking questions like “what sorts of work on the hull are being conducted by a given organization in a given location?” These filters need to be visualized as boxes and arrows graphs, and in DSMs, in parallel. Plexus provides this capability.

#### **4.2 Simulation and Analysis**

Several types of analysis are necessary for the applications we have in mind. These include traditional DSM techniques (partitioning, cycle identification, dependency tearing). As noted above, our model also includes resources, as well as durations for each activity, and these can be augmented with three-point probability distributions, constraints, decision points, and other data. This data can be employed in discrete event simulations to optimize scheduling, and to evaluate resource requirements and the impacts of alternative resource scenarios, and to develop Monte Carlo models of time, cost, and resource implications of uncertainty. The impact of complex iterations on duration, costs, and risk metrics can also be examined in these simulations. Deterministic and probabilistic critical path analysis can also be performed. Plexus provides each of these capabilities, as well as realistic rescheduling if resource scenarios or model details change during actual execution of the model. Being able to exploit each of these simulation and analysis tools are a positive outcome of our model.

### **5 FINAL COMMENTS AND FUTURE GOALS**

We feel we have learned several important lessons in building our model. During our efforts we have worked with many engineers in the ship design community. Responses to our efforts have covered the full spectrum from strongly positive to strongly negative and the range between, but our efforts met with best success once we obtained a collaborative, highly visual boxes-and-arrows modeling tool as a tool for capturing the data we needed for DSM (and other types) of analysis. Another key to our efforts was our careful design of a regulated vocabulary that was used in our modeling workshops.

Future goals of our efforts include: increasing activity data definition to build a reference library of process components, continuing to validate our model and data, exploring simulation and analysis capabilities, including risk and uncertainty. Finally, we look forward to employing the model in the real world planning and understanding a ship design.

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