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Collaborative Engineering Across Organizational Boundaries

ABSTRACT

The design of next-generation undersea weapon systems involves optimizing over many competing disciplines and objectives, and requires a broad range of technical expertise that is not resident within a single organization. Thus, the optimization and development of these systems requires the involvement of multiple government, academic, and commercial organizations. This paper provides lessons-learned as a result of a four-year effort in the Simulation Based Design (SBD) of undersea weapons. During this timeframe, Naval Undersea Warfare Center (NUWC), Naval Surface Warfare Center (NSWC), and Applied Research Laboratory/Penn State University (ARL/PSU) have explored different methods of collaborating across the organizations, and have identified many sources of friction hindering the collaboration. Some are well known, such as file incompatibility between CAD systems. Others are less studied but more fundamental, such as cultural differences between organizations. In order to facilitate collaboration and ultimately support the change in paradigm of acquisition, each must be addressed and resolved.

INTRODUCTION

Rob Gannon, Professor of English at the Pennsylvania State University, has written, "American torpedoes at the beginning of World War II… were primitive dullards with the intelligence of a garden hose (Gannon 1996)." In contrast, modern torpedoes are highly autonomous systems that localize and track targets from the surface to extreme depths, maneuver to intercept evading foes, and overcome countermeasure decoys (Brown 1996). Figure 1 depicts the functional elements of a notional torpedo system. Sensor systems in both the sonar and warhead sub-systems enable the weapon to see friends and foes within the external environment. On-board computer systems provide guidance and control functionality. Propulsion and steering components provide mobility and control. The power sub-system provides the energy for the other sub-systems.

Thus, the development of a new torpedo is a multi-disciplinary design optimization problem (Yukish, Bennett and Simpson 2000). Typically, two approaches have been applied to such problems. One approach uses integration-centric activities such as physical prototyping to coordinate product development efforts. The other approach uses divide-and-conquer strategies such as functional decomposition.

As Figure 1 shows, this second approach is well-suited for the torpedo design problem. The torpedo's subsystems are sufficiently independent to allow individual engineering, with controlled resource allocations and interfaces. From 1997 through 2001, the authors' agencies worked toward the development of a multi-organizational SBD system under the Office of Naval Research (ONR) Undersea Weapon Design and Optimization (UWD&O) initiative (Yukish 2001). A goal of the SBD effort was to create a computer-based distributed collaborative engineering environment, whereby an agency with particular expertise could apply it remotely to the design of the torpedo. Presented here are some of the lessons learned in that work, focusing on the barriers to collaboration in multi-organizational teams.

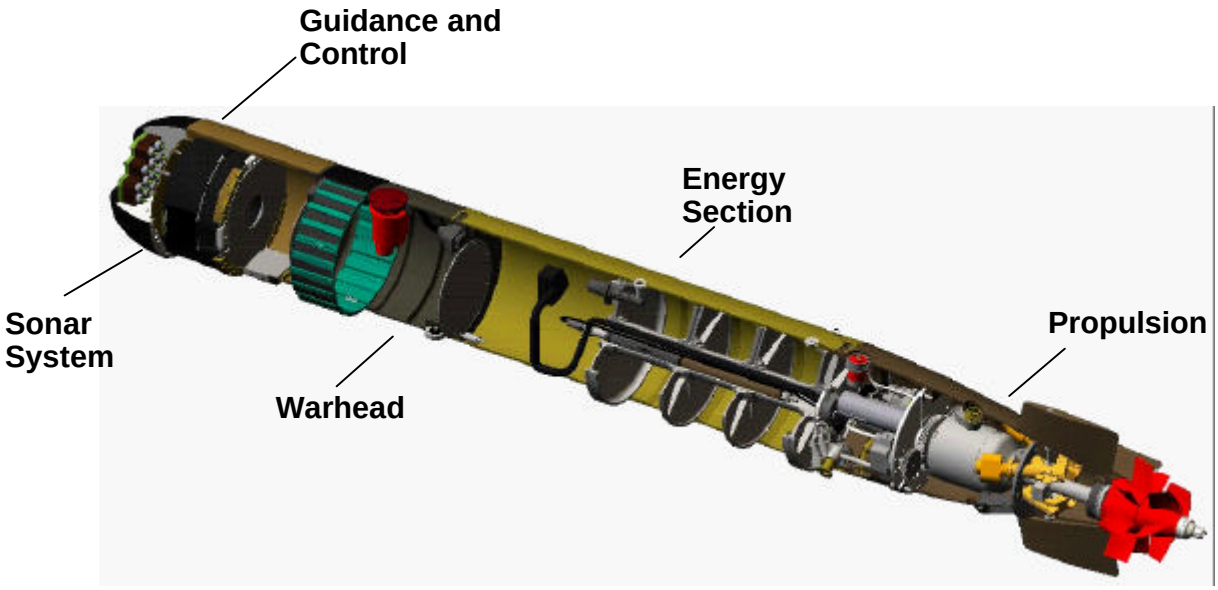

FIGURE 1. Torpedo System Components

COLLABORATION ON ENGINEERING PROJECTS

The Need For Collaboration

Because many of the disciplines and technologies involved in torpedoes have only military applications, expertise tends to be concentrated in Government laboratories, a few closely tied academic institutions, and a few commercial organizations. The customer – the Navy – forms teams of a few to several organizations who must collaborate on the development of the new torpedo. As the perceived threat has shrunk, leading to reduced budgets for torpedo development, the undersea weapons "industry" is responding in two ways. First, development is adopting virtual prototyping principles within the context of a Simulation Based Acquisition environment to identify high payoff engineering solutions and avoid the high cost associated with build-test-build development approaches (Bennett 2001) (Dzielski 2001). Second, as organizations are forced to narrow the scope of expertise they can maintain, team building and collaboration become more critical.

Historical Overview

Collaboration– even on such complex engineering projects– has been around longer than computers (Forsythe). The advantage has always been the allocation of tasks to the people or organizations with the experience and resources to perform them most efficiently. The disadvantage has been the additional management necessary to foster the collaboration, and the time and labor expended exchanging and coordinating information. The Navy's newest torpedo, the Mk 50 Lightweight ASW torpedo, was developed in the 1970s and 1980s, using a typical paper-based collaboration (Allison and Marchese). Program Managers, prime contractors, sub-contractors, system integration agents, design agents, engineers, configuration managers, program analysts, budget analysts, and contracting officers used paper drawings and correspondence (and later, faxes and e-mails) to exchange data. Working groups, committees, panels, and Tiger Teams had to convene meetings to resolve conflicts in interfaces or in allocation of requirements or resources.

For a quarter century, engineers and computer scientists had a vision of a computer-based

"fully collaborative environment" which would overcome many of the problems of paper-based collaboration (Under SECDEF A&T). All data would be available to all workers in real time. All the engineers would see the same representation of the design. Design constraints would be imposed automatically, without human intervention. Approved design changes would be tracked automatically, and would pass instantly into a digital electronic documentation of the current "official" design. The digital description of the design could be coupled directly to engineering analysis, modeling, and simulation tools, evaluating cost and performance. Optimization engines would search the decision space, automatically finding the "best" design.

The astounding growth of the power and speed of computer hardware and software and network infrastructure in the past several years has brought that vision almost fully to reality (Allison and Marchese). Industry, academia, and governments have all developed collaborative environment systems for SBD, starting with special purpose systems with imposed software and data structures, and moving toward generalized systems. Vendors are offering systems that advertise the capability of interfacing with any known engineering software. Standards such as XML and CORBA together with commercial Enterprise Resource Planning (ERP) and Product Data Management (PDM) solutions enable this interconnection.

Current State of Collaborative Environment Systems

These systems have, indeed, solved many of the problems inherent in paper-based collaboration. However, a computer-based collaborative environment not only brings new barriers related to hardware and software, it also accentuates some of the barriers from the paper-based age (Duffy 1998).

The barriers to collaboration fall into two general categories. First are the technical problems associated with integrating diverse, dispersed computational tools and hardware, with the added concerns and requirements for the security of classified information. These issues are unique to computerized collaborative environments. Most issues are already widely known – for example, file compatibility and interconnectivity – and they are not addressed here. Some insights about barriers related to security of classified information and about the costs of computer-based collaboration are offered.

The second type of barrier is cultural or psychological. These are carried over from the paper-based age, and in many cases they are exacerbated by the increased physical separation of individuals, coupled with the decreased barriers to moving information, and by the lack of established processes to guide organizational interaction.

TECHNICAL BARRIERS

Interconnectivity

The most basic barrier to collaborative design environments has to do with establishing interconnectivity between organizations, enabling diverse computer systems and programs to exchange data (Flater and Morris 1999). Although standards currently exist to support the sharing of design information across different operating systems and network protocols, a common understanding of how the design itself shall be decomposed and represented in the digital world must be established to serve as a framework for the development of a single system. While the increased utilization of performance-based requirements has provided design organizations with the freedom to innovate, performance-based requirements tend to complicate inter-organizational collaboration because a baseline representation of the system of interest no longer exists at the start of the program.

From an applications perspective, the increased use of packaged software engineering tools can either streamline inter-organizational collaboration if a de-facto standard emerges, or can act as a barrier if a fundamental

incompatibility exists between the established information systems.

Security

Federal laws and regulations govern protection of National Security information (Under SECDEF R&E). The computers and networks that house classified information must be physically separate from those that contain unclassified information. Data storage media that have been used with a classified system may not be transferred to an unclassified system, even if the media contain no classified information. Transferring information from the unclassified side to the classified side is a fairly streamlined process, but moving unclassified information out of the classified system is difficult. Thus, it is tempting to house a collaborative environment entirely on the classified or unclassified side of the fence as dictated by the highest classification level for program of interest.

Cost Issues

Electronic collaboration environments, like any software-based product, require a significant initial investment to develop the system, but have extremely low variable costs once the system is in place. Treating collaboration as simply an additional program element introduces additional cost earlier in the project lifecycle. Although it is commonplace that initial investment in engineering efforts can dramatically reduce total cost of ownership, this added initial cost burden is difficult to justify in an acquisition setting. The acquisition program assumes both the full cost associated with the development initiative and the risk of potential programmatic delays caused by delays in the availability in the collaboration environment, while receiving only a small portion of the downstream benefit. In the commercial sector, this barrier is commonly addressed by viewing inter-organizational collaboration as an enabling technology for the longer-term strategic partnering between organizations, therefore viewing such an initiative as an investment rather than a task.

PSYCHOLOGICAL BARRIERS

Source of Barriers

The psychological barriers to collaboration are rooted in individual personalities and worldviews. Some people are naturally sharing, deriving great satisfaction from collaborative efforts. Others– perhaps the majority from an inter-organizational perspective– have more competitive personalities, and believe that collaboration is “against the natural order” and that “people will not collaborate unless they are rewarded for it.” While having people with sharing personalities is generally an advantage for collaboration, there is a potential pitfall. People might fulfill themselves by sharing information informally, communicating it to a small group, and bypassing mechanisms set up to ensure that information is universally disseminated. Sequestering of information can lead to “I could have told you that” mistakes. In the fully collaborative environment, sequestering of information is impossible. Any information that is passed within the system is archived and available to all participants.

Competitive personalities, and organizations shaped by them, typically raise familiar barriers to collaboration. These include: information ownership; allocation of design space (e.g., weight, volume, reliability); acceptance of unfamiliar forms and techniques (“not the way WE do it”); and acceptance of efforts of other participants (“not invented here”). These barriers exist in paper-based collaboration as well. The fully collaborative environment heightens concerns about information ownership, but can attenuate the effects of the other psychological barriers.

Collaboration vs. Competition

In the multi-organizational setting, the interaction between the forces of competition and collaboration frequently conflict in an adverse manner (Kraus 1980) (Bleeke and Urnst 1993). This is notable because both of these mechanisms acting independently are intended to resolve conflict in a productive manner. In a

competitive setting, the best concepts transition through the allocation of resources. In a collaborative setting, the best concepts advance through adoption by the community. Although competition and collaboration are not inherently adversarial forces, any situation where natural competitors must collaborate, or vice versa, creates an unnatural tension.

Realistically, individuals view themselves from a variety of perspectives (i.e., an employee of an organization, an engineer, a parent, and a taxpayer) and are capable of both collaborative and competitive behavior. However, in the inter-organizational setting the manner in which individuals approach collaboration is really tied to the dominant perceptions of that activity within the host organization. Thus, an organizational culture that views inter-organizational initiatives as a battle between rivals will likely foster a collaborative environment dominated by affective (i.e., bad) conflict.

Until recently, most technical education programs tended to promote the perception that competency was tied to the delivery of highly specialized, independently-derived work products rather than the production of high quality products by an engineering team. Thus, collaboration in a technical setting tended to work well in cross-functional teams with little duplication of expertise, but often reached an impasse in inter-organizational settings with significant overlap in organizational expertise. For collaborative development efforts, individuals generally tended to accept the current approaches utilized within the organization as "natural" due to the lack of suitable alternative metaphors from their experience base. However, as noted by Russell Knowles (2001):

> "…over the past five years most engineering curriculums in higher education institutions have implemented team building concepts through group projects, so much so that in many cases having group projects in multiple courses causes significant challenges in time availability for scheduling team meetings, a true real world experience... [O]ne thing that remains somewhat allusive to initial investments in collaborative product development programs is formalized team training."

Information Sharing

Implementations with a centralized data repository have been highly successful in inter-organizational settings where relationships are fairly stable and a high degree of coordination is beneficial. However, the free flow of information that is the basis of a collaborative environment obviously contradicts organizations' interests in proprietary information and intellectual property.

The increased emphasis on teaming and collaboration in the current acquisition climate (see above) adds further complications. Entities that previously were (or may still be) competitors now collaborate on projects (Bleeke and Urnst 1993). Furthermore, these entities may be collaborating on some projects, and competing on others. In essence, small organizations form and break up, where the temporary organizations overlap long-lasting organizations. The collaboration problem posed by this situation is to share all of the information between entities to do the task at hand, but share no other information, as it may provide a competitive advantage to the teammate on other ongoing or future programs.

An array of management and legal tools has developed to protect an organization's information ownership in a joint project: complete non-disclosure (for proprietary information), non-disclosure agreements, data rights clauses in contracts, and patent law. Methods to replace these tools in computer-based collaborative environments are evolving. Notably, the commercial sector is addressing the conflict between sharing content (analogous to design data) and applications (computer programs) and protecting intellectual property. Two examples offered here are in the areas of content providers and application providers.

First, in the music, movie, and text publishing industries, there is an ongoing effort to redefine the distribution of their products. The goal is to make the distribution of their content as easy as possible, yet protect their intellectual property. These efforts fall under the broad umbrella of Digital Rights Management (DRM). As with the distribution of collaborative engineering data, the owner wishes to restrict access to the content in a previously agreed upon manner. DRM is an area of active research in terms of both technology and international law. Renato Iannella, Chief Scientist of IPR Systems, has described the issues and a vision of future possibilities (Iannella 2001):

> Previously, Digital Rights Management (DRM) focused on security and encryption as a means of solving the issue of unauthorized copying, that is, lock the content and limit its distribution to only those who pay. This was the first-generation of DRM, and it represented a substantial narrowing of the real and broader capabilities of DRM. The second-generation of DRM covers the description, identification, trading, protection, monitoring and tracking of all forms of rights usages over both tangible and intangible assets including management of rights holders relationships. Additionally, it is important to note that DRM is the "digital management of rights" and not the "management of digital rights". That is, DRM manages *all* rights, not only the rights applicable to permissions over digital content.

Second, sharing of applications (as opposed to content) while maintaining control has traditionally been accomplished via licensing agreements tied to the use of software, and software protections such as FLEXlm, a commercially available license manager (FLEXlm Introduction 2001). Other schemes include hardware protection such as the use of "dongles." A dongle is a hardware data encryption device that physically ties the hardware to the software use (Definition 2001). A new approach, supported to internet technologies, is to access applications via subscription (Tuxedo.org 2001) (Thilmany 2000). In such a setup, the user subscribes to the use of an application, much as a consumer subscribes to cable TV service. The application service provider (ASP) approach was primarily developed to sell services to small and medium-size companies, due to the lower upfront investment. However, it also protects the intellectual property of the ASP by keeping the code under the provider's control, allowing access only through clearly defined interfaces. Therefore, technologies developed for delivering applications via subscription can be used to share applications in a collaborative team, while maintaining control over intellectual property.

Simulation & Engineering Information

One issue is that different organizations are experts of their domain and have simulations to address that domain, which are proprietary in nature and have unique interfaces. A great deal of time and money is spent on developing wrapper technologies and/or integrating commercial tools because these initiatives address known deficiencies and can be resolved in a technical setting. It is unreasonable to assume that an organization would give up intellectual property that serves as their current basis for competition without assurances that their right to benefit from that knowledge will be protected. Interface standards are often viewed as a solution to this dilemma because organizations can retain control of their intellectual property and only need to share information that is essential to the collaborative endeavor. However, such methods demand new skill sets that do not typically reside in most engineering organizations.

CONCLUSION

Inter-organizational collaboration faces both technical and cultural barriers. Near-term technical initiatives will always focus on those solutions that are within their immediate sphere

of influence. However, the topic of inter-organizational engineering collaboration challenges organizations to view collaborative engineering environment from a strategic perspective and consider the longer-term role these environments will play in the competitive landscape. As with any emerging technology, collaborative engineering environments have the potential to impact all facets of the product development environment and, thus, require proactive management on the part of all stakeholders within the undersea weapons community.

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