TITLE: AXIOMATIC DESIGN APPROACH FOR DESIGNING RE-CONFIGURABLE ARCHITECTURE FOR THE C4ISR

SUGGESTED TOPICS: C2 CONCEPTS, THEORY, AND POLICY; MODELING AND SIMULATION; C2 TECHNOLOGIES AND SYSTEMS

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ABSTRACT & BRIEF OVERVIEW OF FULL TECHNICAL PAPER

In recent years, attention has been focused on designing a next generation fighting force that will be flexible, reconfigurable, and lethal, using information systems as the major competitive advantage over an enemy force. According to the Department of Defense (DOD), such architecture is the next generation of integrated Command, Control, Communications, Computers, Intelligence, and Reconnaissance (C4ISR) system for the wired battlefield. While such an idea is extremely powerful, especially when fighting a less organized enemy force in an urban warfare environment, several challenges exist for realizing the design and implementation of such an information system grid. Designing such architecture for the wired battlefield requires first understanding the fundamental requirements of the architecture. Of particular importance is the architecture flexibility, meaning that the architecture must be reconfigurable to adapt to dynamically changing battlefield scenarios.

Zachman [Zachman 1997] has proposed architecture for designing the C4ISR system. Zachman calls the architecture the Framework for Enterprise Architecture. The Framework, as it applies to Enterprises, is simply a logical structure for classifying and organizing the descriptive representations of an Enterprise that are significant to the management of the Enterprise as well as to the development of the Enterprise's systems. It was derived from analogous structures that are found in the older disciplines of Architecture/Construction and Engineering/Manufacturing (ACAEM). The ACAEM classifies and organizes the design artifacts created over the process of designing and producing complex physical products (e.g. buildings or airplanes.) However, Zachman's Framework lacks sound scientific concepts for addressing the complex issues in designing the architecture for the C4ISR system. For example, when the design must fulfill more than one functional requirement, Zachman's Framework fails to handle coupling among the functional requirements. Coupling means that as the design tries to satisfy one functional requirement, other functional requirements are changed also. For example, suppose the goals of designing the logistical support system for the battlefield are: 1) to maximize the service level for the frontline soldiers 2) to minimize the total operational cost. Meeting the first goal of the design should not affect the second goal. If coupling occurs, the design is flawed. The old design must be discarded and a new design created. Also, Zachman's Framework does not address how to design a system whose architecture must be continuously reconfigured. More importantly, the architecture should use the Web as a communication tool for information exchange among the sub-systems of the enterprise.

The IBM's RUP SE (Rational Unified Process Systems Engineering) software package addresses some of the deficiencies of Zachman's work by using the systems engineering approach to design architectures for information technology (IT) infrastructure [Sullivan June 2004]. However, the RUP SE concepts are based on the UML (Unified Modeling Language) approach. The UML is a language for creating application programs. The UML is based on objected-oriented design methodology. According to Rob et. al [Rob et. al 1997], object-oriented design lacks any theoretical foundation.

The SAP (Systems, Applications, and Products in Data Processing) has proposed the Enterprise Services Architecture for designing an IT infrastructure for any enterprise. According to Woods et al. [Woods et al. 2004], *The Enterprise Services Architecture is a road map to help IT take advantage of Web services to gain flexibility and reduce their costs*. The concept behind this architecture is that many business processes use the same collection of enterprise applications. Such enterprise applications can then be grouped together to form composite applications. The composite applications then become the Web services. With a composite application, a user can perform a variety of business processes using the same collection of enterprise applications or Web services to produce a product or deliver some service, for example a simulation support for the C4ISR. This in turn improves flexibility of the IT infrastructure, and it reduces the maintenance cost of the IT. Though this concept is intriguing, Woods et al. did not discuss the design details of the Enterprise Services Architecture.

Using the axiomatic design theory, we propose to establish a new scientific-based methodology for designing reconfigurable architecture for the C4ISR. A brief overview of the axiomatic design is essential for the proposed paper. According to Suh [Suh 1990], design involves a continuous interplay between what we want to achieve and how we want to achieve it." What we want to achieve is the goal of our design, and how we want to achieve it is our physical solution. Suh further explains that we must state the

goals of a design in the functional domain or functional space, and generate the physical solution in the physical domain or physical space, Figure 1. The design procedure then involves interlinking these two domains at every hierarchical level of the design process. The two domains are independent of each other. What relates these two domains is the design. Suh established two fundamental axioms that form the scientific basis of the axiomatic approach to design. They are: ***AXIOM 1***: In a good design, the independence of functional requirements (FRs) is maintained. ***AXIOM 2***: The design that has the minimum information content is the optimal design.

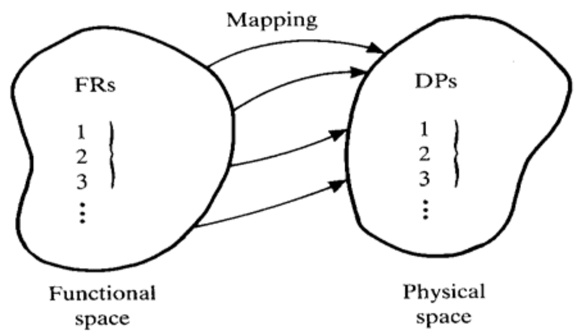

Figure 1. The Mapping From The Functional Space (Or Domain) To The Physical Space (Or Domain), [Suh 1990]. Note that the DPs in the physical space are chosen to satisfy the FRs in the functional domain.

Axiom 1 ensures no coupling occurs between the FRs during the design, and Axiom 2 ensures an optimal design of the product, process, system, or systems-of-systems (SOS). In addition to the functional requirements, a set of constraints may also exist. For example in most design cost is usually the constraint.

We will first discuss the value chain concepts [Porter 1985; Sullivan et al. 2004; Alberts et al. 1999] for enterprise transformation of the Department of Defense [DOD] into enterprise architecture for the C4ISR. From the value chain concepts, we will identify the FRs for the C4ISR. Using the high-level FRs and the appropriate constraints for the C4ISR, we will map the FRs from the functional space to the physical space. We will choose the high-level DPs in the physical space to satisfy the high-level FRs in the functional space. We will then create FR/DP hierarchy through zigzagging between the FRs in the functional domain and the DP in physical domain until we reach the lowest level of the design hierarchy. From the design hierarchy and the design module concepts [Suh 2001], we will construct a flow diagram that represents the architecture of the C4ISR. From the architecture, we will discuss a generic prototype design for the C4ISR, for example information system for the battlefield [Nyamekye et al. June 2004; Nyamekye July 2004; Nyamekye et al. July 2006]. We will discuss how we use Axiom 2 to find the optimal design for the prototype system for the C4ISR. Of particular importance is the scenario where the functional requirements change at different times. We will discuss designing dynamic architecture for C4ISR using axiomatic design theory.

Sullivan [Sullivan et al. 2004] has recently proposed four different views for designing enterprise architecture, namely: Business Architecture (business strategy), Information Architecture (data profile or metadata), Application Architecture (application programs to support business processes) and Technology Architecture (standards, e.g., SOA). We will demonstrate how the new scientific-based methodology addresses these architectural views. Most importantly, we will discuss the Service-Oriented Architecture [Zimmermann et al. 2005] as an emerging concept for designing SOS architecture for service-based modeling and simulation of complex adaptive systems, such as the DOD Global Information Grid [Net-Centric Checklist 2004].

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