13TH ICCRTS

"C2 FOR COMPLEX ENDEAVORS"

Title: INFORMATION CONTENT FOR ADAPTIVE NETWORK PERFORMANCE FOR *C4ISR SYSTEMS-OF-SYSTEMS: QUEUING THEORY AND AXIOMATIC DESIGN APPROACH

SUGGESTED TOPICS: NETWORKS AND NETWORKING; MODELING AND SIMULATION; C2 ASSESSMENT TOOLS AND METRICS

Name Of Author: Kofi Nyamekye, Ph.D.,

Point of Contact: Kofi Nyamekye, Ph.D.

Name of Organization: INTEGRATED ACTIVITY-BASED SIMULATION RESEARCH, INC.

Address: P.O. BOX 421, Rolla, MO 65402

Telephone: 573-647-1702

E-mail address: kofinsoyameye@earthlink.net

*C4ISR (Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance)

© Copyright Integrated Activity-Based Simulation Research, Inc. 2008

ABSTRACT

The paper presents information content for adaptive network performance for C4ISR systems-of-systems (SOS) using queuing theory and axiomatic design approach. The paper first summarizes the network types or configurations, the network classifications and the network properties. It also emphasizes that the network infrastructure is part of integrated systems-of-systems design and not as a stove-piped system. Drawing on the previous author's work, the paper emphasizes that the axiomatic design, integrated with Service-Oriented Architecture-Based Department of Defense Architecture Framework (SOA)-Based DODAF, establishes the scientific framework for designing integrated C4ISR systems-of-systems (SOS), of which the network infrastructure is a subsystem. The queuing models are presented for the network performance, and information content from AXIOM 2 of axiomatic design, is employed for the network optimization. The effect of information overload, on the network performance for the Net-Centric SOS, is also presented. The paper discusses that the Service-based modeling and simulation, and experimental tests are needed to generate the data for the queuing models for network performance and optimization of the C4ISR SOS. Intelligent decouplers that can provide extra bandwidths in the network to reduce information overload, and thus permit the network to dynamically adjust itself to uncertainties, has been discussed. The Design Navigation Method has been discussed for experimental and simulation design, and for optimization, under scenarios of multi-functional requirements (FRs) and interaction effects among the design parameters (DPs). Such an integrated queuing modeling and axiomatic design approach, is critical for designing and operating complex civil-military endeavors.

INTRODUCTION

Network research, which includes network design, performance modeling, and simulation, is an emerging scientific field [NRC 2005]. In fact, the definition of the technical terms for the network science is still unclear. Compounding this issue is the fact that the fundamental knowledge of networks is still primitive [NRC 2005]. A direct quotation from the National Research Council (NRC) report attests to this [NRC 2005]: *"(t)here is a huge gap between what we need to know about networks to ensure the smooth working of society and the primitive state of our fundamental knowledge. This gap makes the military vision of net-centric operations (NCO) problematic, at best."* In recognition of the importance of the network research to NCO and the Army's Future Combat Systems (FCS), and more importantly to counter-terrorism, the U.S. Army requested the National Research Council to study whether a critical need exists for a new fundamental research program in network science. The NRC concluded that five fundamental types of networks exist, namely: the physical network, communications network, information network, cognitive network, and the social network. Rather than providing the full discussion of the network types, we will refer the reader to NRC's report [NRC 2005]. We will only briefly mention the arrangements of these networks as appropriate to network modeling of C4ISR systems.

According to the NRC, the physical network is the first network layer. The communication network is built on top of the physical layer. The information network sits on top of the communication network. Both the cognitive and social networks are built on top of the information network. The NRC points out that real networks may be classified into perhaps four major classes [NRC 2005], namely: Regular Networks, Random Network, Small World Networks, and Scale Free Networks. Their work concurs with the previous work of Atkinson et al. [Atkinson et al. 2005], who have also discussed the theoretical concepts on the network classification. A summary of network properties is essential.

Both NRC and other investigators [Atkinson et al. 2005] say that ***average degree***, ***clustering coefficient***, ***average path length***, are the most important properties for evaluating the behavior of a given network topology [Atkinson et al. 2005; NRC 2005]. The average degree of a network measures the average number of links connected to a node in the network. The clustering coefficient measures how well the neighbors of a given node are linked in the network [Atkinson et al. 2005]. The average path length, through a network, measures the average distance between two nodes of the network chosen at random [Atkinson et al. 2005]. According to Atkinson et al., a network with high average degree, high clustering coefficient, and a low average path length, will achieve overall best performance for any integrated adaptive SOS. A brief summary of the properties of each network class is summarized next.

© Copyright Integrated Activity-Based Simulation Research, Inc. 2008

For Regular Networks, the NRC indicates that average degree of all nodes assumes the same value. Atkinson et al., point out that Random Networks have low average degree, low clustering coefficient, and low average path length. Consequently, they are not appropriate for NCW system design [Atkinson et al. 2005]. They also emphasize that, for the new Command and Control (**C2)** [Alberts et al. 2006], a Random Network is not appropriate for managing the Global Information Grid -- a complex adaptive system. Unlike Random Networks, Small World Networks have high cluster coefficient, and high average degree [Atkinson et al. 2005]. The average path length is low [Atkinson et al. 2005]. Consequently, they are excellent for C4ISR SOS design. The authors also found that Scale Free Networks have high cluster coefficient, low average path length, and a few nodes with a high average degree [Atkinson et al. 2005]. Though the authors' work has significantly contributed to the scientific understanding of the properties of networks for the C4ISR SOS, they did not discuss the scientific models such as the queuing models and simulation models for predicting the performance of the network, and more importantly the performance evaluation of the network for the NCW. Figure 1 shows the probability density function of Small World Network, and Figure 2 the probability density function of a Scale Free Network, in Appendix A.

Alberts et al. [Alberts et al. 2006] have also noted that a hybrid network of a Scale Free Network and a Small World Network might provide the best performance for designing and operating any integrated adaptive SOS such as the integrated C4ISR SOS [Alberts et al. 2006]. They emphasized that such a hybrid network system does not exit today [Alberts et al. 2006]. Thus, it could be useful to study the performance of such a network configuration in Net-Centric SOS.

Perry et al. have provided a quantitative model for predicting the response time as the basis for quantifying the benefit of collaborating across an information network, such as in NCW [Perry et al. 2002]. We should emphasize that Perry et al.'s work is a generic queuing model for a given network configuration for the battlefield, especially for the NCW. They also showed that enhanced collaboration causes information overload, increasing the average response time or latency. They included a complexity penalty in their queuing model to account for the fact that additional network connectivity leads to such information overload effects. They called it the negative effect of collaboration in NCW. The network overload leads to an increase in effective latency on the critical path. Despite the significance of their work in NCW, they did not include in their model the nodal processing times, and other parameters such as the total network load (or external traffic entering the network), all of which also affect the delay time. More importantly, they only considered the nodal processing times and not the channel delays. Channel delays are important because they can increase the network overload. Moffat [Moffat 2003] has borrowed from Perry et al.'s work [Perry et al. 2002] to establish the queuing model for the collaboration among the different nodes in an information network for the NCW. However, similar to Perry et al.'s work, Moffat's model only showed the nodal processing times; his model did not include the channels' delay times, and the propagation delay. Consequently, any generic queuing models for predicting the network performance must include channel delays.

Though not directly related to the NCW, previous researchers in Integrated Manufacturing Production Systems [IMPSs] have extensively addressed the network issues in designing and operating IMPSs [Chang and Nyamekye 1993]. Originally envisioned by Boeing and General Motors in the early 1980s, the Manufacturing Automation Protocol/Technical and Office Protocol (MAP/TOP) information technology architecture [Jones 1988] was considered to be then the standard architecture for integrating heterogeneous distributed manufacturing enterprise systems-of-systems or Computer-Integrated Manufacturing (CIM). Though the MAP/TOP concept was very intriguing, it never materialized [Black 1991]. The proponents of MAP/TOP quickly realized that redesigning the manufacturing processes of a manufacturing enterprise into cellular manufacturing and integrating quality control to consistently achieve superior quality products must be addressed first before implementing any information technology [Black 1991]. This issue is critically important in C4ISR SOS, because the Service-Oriented Architecture (SOA), similar in concept to MAP/TOP, has now become the standard architecture for designing and networking the C4ISR SOS. In fact, the new Department of Defense Architecture Framework (DODAF) Version 1.5 [DODAF Version 1.5, Volume II April 2007], which the author coins it as (SOA)-Based DODAF, includes SOA as the requirement for designing any SOS to achieve NCW. The DODAF has become the mandatory architecture for designing NCW and thus the DOD Global Information Grid (GIG). Most importantly, the DODAF replaces the previous C4ISR Architecture Framework [DODAF Version 1.0,

Volume I February 9 2004]. Today, many enterprises using SOA have realized that unless the business processes of an enterprise are redesigned efficiently, implementation of SOA would not produce any economic benefit to the enterprise [Roberts May 17 2007]. In fact, the scorecard of a well-respected enterprise that has adopted SOA concepts for the past eight years has recently concluded that the SOA implementation is a business process issue more than a technology issue [Roberts May 17 2007].

To date the most extensive work on network design and performance is by Kleinrock [Kleinrock 1975]. As a member of the scientific research team on ARPANET [Kleinrock 1975], he designed the queuing models and simulation models for designing and operating the performance of communication networks. In fact, his work and other research scientists in ARPANET's research program led to the creation of the Internet [Anthes July 4 2005]. Furthermore, Kleinrock, and his collaborators designed experimental tests to validate the models and simulation efforts. They found the results from experimental tests to be in agreement with the queuing models and simulation efforts. This paper is an extension of the Kleinrock's work to include the effect of collaboration among the different nodes in an information network on information overload of the network, that is, to include the complexity penalty, as proposed by Perry et al. [Perry et al. 2002].

Consequently, the organization of the subsequent sections of this paper is as follows. First, we will discuss the axiomatic design and emphasize information content, AXIOM 2, as the scientific base for analytical model for network performance analysis, using queuing model results. Second, we will establish the theoretical queuing models to predict the performance of networks. Of particular importance are the following performance measures: system response, throughput, resource capacity, and resource utilization. The concept of propagation velocity as envisioned by Kleinrock in increasing the response time would also be included in the model. The model would include the complexity penalty, as we previously noted.

As we discussed before, the network is part of any integrated C4ISR SOS. In addition, in complex adaptive systems, for example in integrated adaptive supply-chains of which C4ISR SOS is an example, interdependencies exist among the business processes and the network subsystems [Brooks December 2005/January 2006]. For example, if the business/warfighter processes in DOD integrated supply chain generate excessive information outputs, which exceed the network capacity, congestion in the network can occur. Thus, the network must be treated as a subsystem within an integrated adaptive value systems-of-systems (integrated supply chains), and not as a stove-piped system in the C4ISR SOS. Third, we will discuss that the principles of ***Power To The Edge*** establish "design and architecture of systems-of-systems," and "organization and management of work" [Alberts et al 2003]. Most importantly, the "design and architecture of systems-of-systems" must first be established before "organization and management of work" can occur. Using the new (SOA)-Based DODAF [DODAF Version 1.5, Volume II April 2007] and borrowing from the recent work by Nyamekye in axiomatic design of C4ISR systems [Nyamekye June 2007], we will discuss the generic blueprint for C4ISR systems-of-systems design, within which the networks would operate as subsystems for the C4ISR ecosystem. Using the queuing models, we would then discuss the Service-based simulation efforts and experimental tests that could be run to generate the test data for the performance evaluation. AXIOM 2 (from axiomatic design [Suh 1990]), which measures the total information content of large-scale distributed enterprise systems, would be discussed to predict the performance of the C4ISR SOS. Conclusions and potential applications for complex civil-military endeavors will follow.

AXIOMATIC DESIGN

A brief overview of the design loop proposed by Wilson as the framework for discussing axiomatic design is essential, Figure 3. Suh, the architect of axiomatic design, previously used Wilson's framework [Wilson 1980].

According to Wilson, a design process begins with the establishment of the *functional requirements* (FRs) to fulfill a given set of needs. The design then ends with the creation of an entity (a product, a system, systems-of-systems, or a process) that fulfils the *functional requirements*. Figure 3 shows the design process. The design process begins with the recognition of the *societal need*. Typically, the *societal need*

© Copyright Integrated Activity-Based Simulation Research, Inc. 2008

is usually unclear. For example, the U.S. Army's need may be to achieve Information Age Transformation [TRADOC], but it may not be clear with the details of such a need, for example, the need for scientific research programs such as the Network Science required [NRC 2005] for achieving it. The need is then coded into a concrete *set of functional requirements*. In the Information Age Transformation, a *specific functional requirement* in the *set of functional requirements* may be -- "Create an adaptive robust Net-Centric Value Systems to support high-tempo of operations in any battlefield, including asymmetric warfare." After the need is coded, ideas are generated to create the product or system. In the Information Age Transformation example, the final system may be -- "Future Combat Systems (FCS)." The product or system is analyzed and the performance measures compared with the original *set of functional requirements* through a feedback loop. When the product or system does not fully satisfy the original *set of functional requirements*, then we must reformulate new ideas or change the *functional requirements* to be accurately consistent with the *societal need*. We continue this iteration until we create an acceptable system. The final product or system is tested in the marketplace or in the battlefield.

We should emphasize that when the *societal need* changes, the system may not be adequate to meet the new need. Consequently, we must go through the design loop again to redesign the existing product or system or completely design new product or system.

Recognizing that for centuries design has been treated as an art, the National Science Foundation (NSF) funded a research program at the Massachusetts Institute of Technology (MIT) in the early 1980s to establish the scientific basis for design [Suh 1990].

Under a major grant from NSF, Suh and his coworkers conducted a major research program that led to the establishment of axiomatic design theory [Suh 1990]. According to Suh, "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, Figure 4. 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 4. 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.

To begin any design, we must determine the design's objectives by defining it in terms of specific requirements, called the functional requirements (FRs). Then, to satisfy these functional requirements, we must create the design solution in terms of design parameters (DPs). The design process involves relating these FRs of the functional domain to the DPs of the physical domain, Figure 4. 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.

AXIOM 1 simply states that in designing any system, we must meet the goals (strategic or tactical requirements) of the system independently. For example, suppose the goals of designing an information visualization system are: 1) maximize the information benefits per unit cost and 2) minimize the total operational cost. According to AXIOM 1, the final design must satisfy both goals independently. Meeting the first goal should not affect the second goal. AXIOM 2 says that among the different designs that will meet both goals, the design that will require the least amount of information to describe it or will achieve the highest reliability of the system will be the best design. AXIOM 2 establishes the theoretical foundation for an optimum design of a product, process or a system, for example software, organization and so on. We should note that classical optimization models, from operation research field, do not generally yield optimum results when more than one criterion for which the system must be optimized, exist [Nakazawa and Suh 1984]. For example, when the goals of designing logistics system are both maximizing customer Service and minimizing the distribution costs, classical optimization models do not achieve optimum results. Consequently, axiomatic approach is superior to the traditional optimization techniques when the design must meet more than one goal, concurrently. Furthermore, we can use axiomatic design to evaluate an existing design for improvements.

© Copyright Integrated Activity-Based Simulation Research, Inc. 2008

In addition to the functional requirements, a set of constraints may also exist. Constraints are factors that establish the boundary on acceptable design solutions. For example, some designers treat cost as a constraint. On the battlefield, how much collateral damage, and how many casualties are "acceptable" in a theater operation, could represent the constraints [Alberts et al. 2003]. Constraints are very similar to functional requirements in character and attributes except that the independence of constraints is not required in a good design.

AXIOM 2 then establishes the scientific base for network performance model for the C4ISR systems-of-systems. Equation 1 shows the basic relationship for information content per AXIOM 2 [Suh 1990].

$$I = \log\left(\frac{system\ range}{common\ range}\right) \qquad \text{Equation 1}$$

I = Information content

$System\ Range$ = Capability of activity or Service given in terms of tolerances; $Common\ Range$ = The amount of overlap between the design range and the system range.

Equation 2 shows the total information of the global system, such as a value system (integrated supply chains).

$$I_{value\ system\ or\ global\ system} = \sum I \qquad \text{Equation 2}$$

Figure 5 provides the details for Equation 1. The functional requirement represents the performance measure of a system, activity, or Service. "Engage an insurgent," is an example of an activity. The design parameter (DP) specifies the operating condition of a system, activity, or Service. The design parameter must be set to achieve the performance measure or functional requirement (FR) of a system, activity, or Service. "Engagement distance of warfighter," is an example of a design parameter. The *design range* is the tolerance of the performance measure or functional requirement (FR) associated with DP specified by the designer, and the *system range* is the capability of a system, activity, or Service given in terms of tolerances. The designer specifies the *design range*. An example of the *design range* is "100 to 200 number of insurgents be defeated in any engagement." Depending on the uncertainties in the mission, such as the terrain, the insurgents' environment such as densely populated urban environment, the actual number of insurgents defeated may be different. For example, it may be "80 to 120." Please note that the constraint may be "zero to one collateral damage – civilians hurt." When the *system range* overlaps the *design range*, and the constraints are not violated, the system, activity or Service, will achieve the desired performance. Otherwise, the capability of the system, activity, or Service is not acceptable.

Figure 6 shows the details of the total information content of the value system, Equation 2. The total minimum information content is not the same as the minimization theories in operations research, where a single value must be achieved. In axiomatic theory, we are interested in the range of performance values of the system, activity, or Service that fall within the enterprise or the designer's specifications, under some given constraints or policies established by the enterprise or the designer. Alberts et al. have proposed that such a measure of performance on the battlefield is far superior to the traditional optimization methods where the maximum or minimum value involves one data point rather than a range of values [Alberts et al. 2003].

QUEUING MODELS

As noted before, our queuing model draws on the previous work of Kleinrock in ARPANET. The ARPANET, developed by Defense Advanced Research Agency (DARPA), was the world's first

© Copyright Integrated Activity-Based Simulation Research, Inc. 2008

operational packet switching network and the predecessor of the global Internet. Today the Transmission Control Protocol/Internet Protocol (TCP/IP) owes its roots to ARPANET. Thus, it is fitting to borrow from Kleinrock's queuing models for this paper. We should emphasize that the queuing models, discussed in the subsequent sections for the performance evaluation of C4ISR SOS, are quite extensive. Thus, for readers, interested only in the final equation for the queuing models (Equation 20), can skip the next sections and continue from the last paragraph (before the section heading "DESIGN OF C4ISR SYSTEMS-OF-SYSTEMS") on Page 12, without any loss of readability.

Much literature exists on queuing theory. Rather than providing in depth discussion, we will briefly discuss the basic theory. For further details, please refer to Kleinrock's work on queuing theory [Kleinrock 1975]. A brief overview of the network infrastructure configuration, borrowed from (SOA)-Based DODAF documentation [DODAF Version 1.5, Volume II April 2007] would be helpful before discussing the basic queuing theory. Consider Figure 7, which depicts communication systems, communication links, and communication networks. Communication systems are systems whose main function is to control the transfer and movement of system data. Switches, routers, and communication satellites are examples of communication systems. Please note that in Figure 7 the small boxes represent communication systems, as do the satellites icons. A communications link is a single physical connection (or channel) from one system (or node) to another. A communications path is a (connected) sequence of communications systems and communications links originating from one system (or node) and terminating at another system (or node). A communications network, defined previously, may contain multiple paths between the same pair of systems. The term *interface* used in Figure 7 represents an abstraction of one or more communications path(s). The NODE A, B, C, and so on represent the subsystems or systems that may be data storage nodes, intelligent nodes that can perform mission application processing, such as the futurist net-centric nodes, or other Services for the warfighter operations. Typically, communication systems do not perform mission application processing. However to assist in modeling collaborative efforts among the nodes in NCW, we will assume that the communication systems are also intelligent systems or nodes that can perform mission application processing, in addition to controlling the transfer and movement of system data.

Assume that the network infrastructure, Figure 7, can be represented as O-channel, P-node model [Kleinrock 1975]. We assume that the O communication channels or links are noiseless, reliable, and each channel represented as i_{th} channel, has a capacity of F_i (bits per second) [Kleinrock 1975]. Please note the same queuing model is valid for information network, which Perry used for his effort. The P-nodes represent intelligent processing nodes that can perform a variety of functions such as message or packet switching, message reassembly, routing, buffering, acknowledging, futuristic NCW chores, and so on. We represent the mean of each nodal processing time to be K_z. We will discuss the mean nodal processing time, later. Traffic enters the network from external sources, such as sensor systems. The traffic arrival follows the Poisson process, with a mean arrival rate represented by γ_{jk}, for the messages originating at node j and ending at the final destination k [Kleinrock 1975]. That is, the probability density function of the traffic arriving the network is a Poisson distribution. Equation 3 defines the total external traffic entering and leaving the network [Kleinrock 1975].

$$\gamma = \sum_{j=1}^{P} \sum_{k=1}^{P} \gamma_{jk} \qquad \text{Equation 3}$$

Equation 3 stems from the fact that the ith node receives from outside the network a sequence of arrivals from an independent Poisson source at an average rate of $\gamma_i = \sum_k \gamma_{ik}$ (messages per second) [Kleinrock 1975]. In addition, we will assume that all messages have lengths that are drawn independently from an exponential distribution with mean $\frac{1}{\mu}$ (bits) [Kleinrock 1975]. Please note that we

have ignored the concept of packets in packet switching in Equation 3. We will consider the concept later. Furthermore, we will assume that each node has infinite storage capacity [Kleinrock 1975].

Kleinrock points out that in high-speed networks that span across many geographical areas, the propagation time, PT_i, may be significant, and thus should be included in the queuing model. The propagation time is the time required for the energy representing a single bit to propagate down the length of the ith channel [Kleinrock 1975], at the speed of SP (miles per hour). Thus, if the length of the ith channel is L_i, then, $PT_i = \frac{L_i}{SP}$ [Kleinrock 1975]. Furthermore, he notes that if the length of the message is represented as LM (bits), the resident time of the message in the ith channel is then, $PT_i + \frac{LM}{K_z}$. Please note that we consider each channel in the network as a separate server or a Service center [Kleinrock 1975]. With this in mind, we can let λ_i represent the average number of messages per second traveling through the ith channel. Thus, similar to the external traffic (Equation 3), Equation 4 then defines the total traffic within the network as follows [Kleinrock 1975].

$$\lambda = \sum_{i=1}^{O} \lambda_i \qquad \text{Equation 4}$$

In network simulation and modeling, one of the critical performance measures is the total average message delay, average response time, or latency, represented as T. Suppose we let Q_{jk} represent the mean message delay for a message that originates from node j and ends at node k [Kleinrock 1975]. Then, Equation 5 represents the total average message delay in the network [Kleinrock 1975].

$$T = \sum_{j=1}^{P} \sum_{k=1}^{P} \frac{\lambda_{jk}}{\gamma} Q_{jk} \qquad \text{Equation 5}$$

The ratio, $\frac{\gamma_{jk}}{\gamma}$, in Equation 5, represents the fraction of the total entering message traffic that will experience some average delay Q_{jk}. We should emphasize that Equation 5 represents a decomposition of the network in terms of origin-destination pairs [Kleinrock 1975].

To evaluate the message delay, suppose we let ζ_{jk} represent the path that the messages which originate at node j and reach the destination node k [Kleinrock 1975]. Suppose the messages transverse the ith channel of capacity (F_i) in this path, then, the ith channel must be included in the path ζ_{jk} [Kleinrock 1975]. We can say that the channel capacity F_i is a member element of the path ζ_{jk}. That is, $F_i \in \zeta_{jk}$ [Kleinrock 1975].

Consequently, the average rate of message flow, λ_i, from Equation 4, on the ith channel, must be equal to the average message flow rates of all paths that pass through this ith channel [Kleinrock 1975]. Equation 6 shows such a relationship.

© Copyright Integrated Activity-Based Simulation Research, Inc. 2008

$$\lambda_i = \sum_j \sum_k \gamma_{jk}$$ Equation 6

The mean message delay, Q_{jk}, given in Equation 5, then becomes average delays that a message experiences in traversing all the individual channels along the path ζ_{jk}. Thus, we can let T_i represent the average time that a message spends waiting for and using the ith channel. Please note that the channel is equivalent to the "server" that is typically used in the traditional queuing model. Furthermore, in traditional queuing model we treat the "server" as a "system". Thus, we can say that T_i is the average time that a message spends "in the system" where the system here means the ith channel (a server) plus the queue of messages in front of the ith channel. This is the fundamental concept of using the queuing theory to model network performance. Thus, we can write the message delay, Q_{jk}, along the path ζ_{jk}, as $Q_{jk} = \sum_{i:F_i \in \zeta_{jk}} T_i$ [Kleinrock 1975]. Substituting, the relationships into Equation 5, yields the total average message delay in the network as follows, Equation 7.

$$T = \sum_{j=1}^{P} \sum_{k=1}^{P} \frac{\gamma_{jk}}{\gamma} \sum_{i:F_i \in Q_{jk}} T_i$$ Equation 7

Exchanging the order of summations and realizing that the condition on i becomes the corresponding condition on the pair j,k as typical in mathematical sciences in interchanging the summation in Equation 7, we can rewrite Equation 7 to become Equation 8 [Kleinrock 1975].

$$T = \sum_{i=1}^{O} \frac{T_i}{\gamma} \sum_j \sum_k \gamma_{jk}$$ Equation 8

Substituting the expression of λ_i from Equation 6 into Equation 8, yields Equation 9.

$$T = \sum_{i=1}^{O} \frac{\lambda_i}{\gamma} T_i$$ Equation 9

Equation 9 is very intriguing. It says that in any network (e.g. communication network, information network, etc.) we can model the total average message delay in terms of single components, namely, T_i. That is, each embedded channel in the network, can offer a solution identical to the same channel acting independently from the network but with Poisson arrivals at a rate equal to that offered by the network [Kleinrock 1975]. Thus, the issue then becomes solving for a message's average system time in a single channel that is deeply embedded within a network [Kleinrock 1975]. According to Kleinrock, the issue is not that simple for network modeling, because dependence exists among the inter-arrival and Service times of the messages. Kleinrock noted that the natural phenomenon of messages arriving in sequence on a given channel and departing on some other given channel in the same sequence creates such dependence [Kleinrock 1975]. Contrary to this notion, Kleinrock argued that if messages leaving a node on a given channel had entered from distinct channels or if messages entering the same channel depart on distinct channels then such dependence would be negligible. According to Kleinrock, much data from simulation results confirm that such an argument is indeed true. To affirm this statement, Kleinrock made the following assumption [Kleinrock 1975].

© Copyright Integrated Activity-Based Simulation Research, Inc. 2008

INDEPENDENCE ASSUMPTION: Each time a message is received at a node within the network, a ***new length, á****, is chosen independently from the probability density function (pdf)*

$$p(a) = \mu e^{-\mu a} \qquad a \geq 0$$ *Equation 10*

Equation 10 says that each time a node receives a message; we generate a new length of a message. Of course, such an assumption is invalid because messages do not change their length as the move through the network [Kleinrock 1975]. However, Kleinrock points out that such an assumption has very negligible effect on performance measure, T, total average message delay, based on previous studies. Thus, it is fitting to use it to establish a single channel analysis. With such as an assumption we can represent the ith channel as the classical $M/M/1$ system with Poisson arrival λ_i and exponential Service times of mean $\frac{1}{\mu F_i}$ sec [Kleinrock 1975]. From the traditional queuing model, we can represent, T_i, the average message delay in a single channel as follows.

$$T_i = \frac{\frac{1}{\mu}}{1-\rho}$$ Equation 11

The ρ, in Equation 11, is the mean average time a message uses the channel, that is the resident time in the channel. The relationship ρ is: $\rho = \frac{\lambda_i}{\mu F_i}$. Substituting the relationship for ρ into Equation 11, and $\frac{1}{\mu F_i}$ for $\frac{1}{\mu}$ (in the numerator of Equation 11), and simplifying, yields Equation 12.

$$T_i = \frac{1}{\mu F_i - \lambda_i}$$ Equation 12

Substituting T_i from Equation 12 into Equation 9, and simplifying Equation 9, yields Equation 13.

$$T = \sum_{i=1}^{O} \frac{\lambda_i}{\gamma}\left[\frac{1}{\mu F_i - \lambda_i}\right]$$ Equation 13

We emphasized earlier that we would initially neglect the nodal processing time, K_Z, and the propagation delay, PT_i, but later include them to complete the queuing network model. Kleinrock emphasized from the ARPANET's work that in addition to the message traffic moving through the network, certain amount of control traffic exists [Kleinrock 1975]. Thus, to establish the true massage traffic for a single channel we must split the message delay into two parts, namely: a waiting time on queue and a Service time. According to Kleinrock, the Service time has an average value that relates to the average length of the true data. The waiting time results from the interference from all other traffic in the network, and it (waiting time) consists of partly data traffic and partly the control traffic [Kleinrock 1975]. Thus, we if let $\frac{1}{\mu}$ represent the average length of a data packet, and $\frac{1}{\mu'}$ represent average length of all packets,

respectively, the true expression for T_i, Equation 12, then becomes Equation 14. Please note that the first term in Equation 14 is the message delay due to the waiting time on queue and the second term the delay due to the Service time.

$$T_i = \frac{\frac{\lambda_i}{\mu' F_i}}{\mu' F_i - \lambda_i} + \frac{1}{\mu F_i} \qquad \text{Equation 14}$$

Substituting Equation 14, the nodal processing time, K_z, and the propagation delay, $PT_i = \frac{L_i}{SP}$, into Equation 9, yields the relationship in Equation 15 for the total average message delay, T, in the network.

$$T = K_z + \sum_{i=1}^{O} \frac{\lambda_i}{\gamma} \left[\frac{\frac{\lambda_i}{\mu' F_i}}{\mu' F_i - \lambda_i} + \frac{1}{\mu F_i} + \frac{L_i}{SP} + K_z \right] \qquad \text{Equation 15}$$

Equation 15 is generic queuing model for evaluating the network performance. The term in the bracket represents the new modified expression for T_i. Furthermore, we can use Equation 15 to establish the critical path length – along the path from node j to node k. Kleinrock has established such a relationship. We have omitted it in this paper. For details about such a relationship, please refer to Kleinrock's work [Kleinrock 1975]. The additional term outside the bracket accounts for the fact that messages travel through an extra node than they do for the channels as the messages go through the network. As noted before, Moffat [Moffat 2003] has borrowed from Perry et al.'s work [Perry et al. 2002] to establish the queuing model for the collaboration among the different nodes in an information network for the NCW. However, similar to Perry et al.'s work, Moffat's model only showed the nodal processing times; he did not include the channels' delay times, and the propagation delay. We can modify Equation 15 to account for the nodal time, as proposed by Moffat. Suppose we assume the probability density function of the processing time at a node z to be exponential distribution, with a mean processing time, $\frac{1}{\sigma_z}$, then Equation 16 gives the mean node processing time as follows.

$$K_z = \frac{1}{\sigma_z} \qquad \text{Equation 16}$$

Using Equation 16, we can include collaborative efforts of other nodes r (not necessarily in the path containing z), with node z, in the network for the NCW, Equation 17.

$$K_z = \frac{1}{\sigma_z} \left\{ \prod_{r=1}^{\deg z} (1 - K_r))^{\omega_r} \right\} \qquad \text{Equation 17}$$

The K_r value is a measure of the entropy [Shannon et al. 1949] associated with the knowledge that node r, contributes to node z in the collaborative efforts, for example, creating a common operating picture (COP), for the warfighter. Perry et al. say that for high quality of collaboration, $K_r = 1$. The factor ω_r is assumed to be 1, if r is one of the nodes directly involved in the time-critical operation (but not on the path, containing node z). It is assumed 0.5 if node r is one of the other network nodes, to reflect a lower level of collaboration with these nodes. The $\deg_z$, represents the average number of links from

nodes r, that are contributing to the collaborative efforts to node z in the network. It is the ***average degree***, noted before. Substituting Equation 17 into Equation 15, we get Equation 18.

$$T = \frac{1}{\sigma_z}\left\{\prod_{r=1}^{\deg z}(1-K_r))^{\omega}r\right\} + \sum_{i=1}^{O}\frac{\lambda_i}{\gamma}\left[\frac{\frac{\lambda_i}{\mu' F_i}}{\mu' F_i - \lambda_i} + \frac{1}{\mu F_i} + \frac{L_i}{SP} + \frac{1}{\sigma_z}\left\{\prod_{r=1}^{\deg z}(1-K_r))^{\omega}r\right\}\right] \qquad \text{Equation 18}$$

Perry et al. have also noted that we should include a complexity penalty to account for the fact that additional network connectivity leads to information overload effect. They suggest that we should multiply T in Equation 18 by the complexity value $\frac{1}{1-g(C)}$. They emphasize using Equation 19 to estimate the value of $g(C)$. The C is the total number of connections that the nodes access on the path, that is, $C = \sum_{z=1}^{O+1}\deg_z$. Please note that the number of nodes in the path equals the number of channels plus one, as previously discussed. Thus, the upper limit of the summation sign is $O+1$.

$$g(C) = \frac{e^{a+bC}}{1+e^{a+bC}} \qquad \text{Equation 19}$$

Letting T_c to represent the average response time due to information overload in integrated Net-Centric SOS, and applying the complexity value, $\frac{1}{1-g(C)}$, to Equation 18, we get the relationship for the T_c, Equation 20.

$$T_C = \frac{T}{1-g(C)} \qquad \text{Equation 20}$$

Equation 20 establishes the relationship for modeling the network performance of Net-Centric system-of-systems, such as the integrated C4ISR systems-of-systems. The subsequent sections discuss the C4ISR SOS, followed by information content for network performance evaluation. The discussion of simulation models and experimental tests will then be in order.

DESIGN OF C4ISR SYSTEMS-OF-SYSTEMS

Figure 7 shows that the network infrastructure is part of any integrated C4ISR SOS. In addition, in complex adaptive systems, for example in integrated adaptive supply-chains, interdependencies exist among the business processes and the network subsystems. For example, if the business/warfighter processes in DOD integrated supply chain generate excessive information outputs, which exceed the network capacity, congestion in the network can occur. Thus, the network must be treated as a subsystem within an integrated adaptive value systems-of-systems (integrated supply chains), and not as a stove-piped system in the C4ISR SOS. As previously discussed, the principles of the ***Power To The Edge*** can be applied in two ways:

- Design and architecture of systems-of-systems
- Organization and management of work

However, the "design and architecture of systems-of-systems" must be established first before "organization and management of work" can occur [Alberts et al. 2003, Alberts et al. 2006, Alberts et al.

2007]. The "design and architecture of systems-of-systems" is noteworthy. When we examine the legendry Toyota adaptive integrated supply chains and Wal-Mart integrated adaptive ecosystems, it is quite the clear that both superior ecosystems follow the principles of the ***Power To The Edge***. In fact in both ecosystems, much effort is spent in "design and architecture of systems-of-systems" for achieving agility of every subsystem, and thus integrated systems-of-systems. The "organization and management of work" is a closed loop command and control system, and interactive, between all levels of the ecosystems. For example at Toyota, the unity is command – superior quality, on-time delivery, and low-cost -- is propagated throughout Toyota's ecosystem. The edge subsystems (cellular manufacturing systems) manage (control) among themselves to produce part components or products to fulfill the unity of command. It is very intriguing to note that unlike many enterprises, where the senior management and middle managers create the workers' schedules, the shop floor managers and the workers at the edge of the enterprise (cellular manufacturing levels) and its partners, create the schedules. The floor managers and workers use the kanban flow – management information system (sense-and-respond system) that controls the inventory of parts, to manage the edge subsystems [Monden 1983]. Another intriguing point to emphasize here is how Toyota practices self-synchronization on the shop floor. In Toyota Production System, each worker on the shop floor is a mobile agent. He or she periodically checks the health of each machine in his or her own production line as well as the health status of other production lines through information transfer boards, known as andon lights [Monden 1983], positioned between successive production lines. When a machine breaks down, the worker publishes the problem to all workers on the shop floor by turning on a switch on an adjacent information transfer board that broadcasts the problem. Upon seeing a particular production line with the problem, other workers leave their production lines to assist the worker to fix the problem. The workers return to their respective production lines after helping the particular worker to fix his or her problem. No middle manager is involved in controlling the factory floor, during normal and emergency situations. Thus, the principles of the ***Power To The Edge*** are revolutionary concepts that must not only be applied to the design and management of C4ISR SOS, but also to the design and management of any integrated adaptive systems-of-systems.

Despite the visionary work of Alberts et al. [Alberts et al.], the architects of the principles of the ***Power To The Edge***, they did not establish the scientific base for designing Service-based integrated systems-of-systems. Using axiomatic theory and the Service-Oriented Architecture-Based (SOA)-Based DODAF, Nyamekye has recently established the scientific foundation for designing the integrated C4ISR SOS [Nyamekye June 2007]. Thus, we will borrow from the recent work of Nyamekye to discuss the design of C4ISR SOS, which includes the network infrastructure as a subsystem [Nyamekye June 2007]. Among the corollaries and theorems derived from AXIOM 1 and AXIOM 2, the following four corollaries and a theorem, are essential for designing the C4ISR systems-of-systems, namely [Suh 1990; Suh 2001]:

Corollary 1: Decoupling of Coupled Design: Decouple or separate parts or aspects of a solution if FRs are coupled or become interdependent in the proposed designs.

Corollary 2: Minimization of FRs: Minimize the number of functional requirements and constraints. Strive for maximum simplicity in overall design or the utmost simplicity in physical and functional characteristics.

Corollary 3: Integration of Physical Parts: Integrate design features into a single physical process, device, or system when FRs can be independently satisfied in the proposed solution.

Corollary 4: Use of Standardization: Use standardized or interchangeable parts, architecture, process, device, or system if the use of these parts, architecture, process, device, or system is consistent with the FRs and constraints.

THEOREM M2 (Large System with Several Subunits) When a large (e.g., organization) consists of several subunits, each unit must satisfy independent subsets of FRs so as to eliminate the possibility of creating a resource-intensive system or a coupled design for the entire system.

Corollary 1 states that functional independence must be ensured by ***decoupling*** if a proposed design couples the FRs. ***Decoupling*** does not necessarily imply that a part or system has to be broken into two or separate parts or systems, or a new element has to be added to the existing design [Suh 1990]. Functional decoupling may be achieved without physical separation, although in some cases such physical decomposition may be the best way of solving the problem [Suh 1990]. The implication of Corollary 1 is that in designing a part, software as a Service (SAAS), a process, or systems-of-systems, we must ensure that the proposed design serves the goals independently. For example, in SOS that is designed from SOA principles, a Service consumer, such as the server of an enterprise, can use a Service created by another enterprise to achieve the business goals of the Service consumer's enterprise independently of the language which the Service provider chooses to create that Service to serve the Service provider's own business needs. Corollary 2 states that as the number of FRs and constraints increase, the part or system becomes more complex. Complexity raises the information content. The implication of Corollary 2 is that if two or more functions serve the same goals, we must combine them into a single FR to reduce the information content of the design. Corollary 2 is the scientific foundation for designing Lean Six Sigma SOS. Today, the U.S. Army has adopted the Lean Six Sigma, as its vision for designing and training its force structure as an integrated, flexible, efficient and rapid force structure for counter-insurgency operations in Iraq [Marx May 9 2006]. Corollary 3 states that the number of physical processes, devices, or systems should be reduced in order to decrease information content of the design. Heterogeneous Services exist in distributed Service-based SOS. To integrate such Services, Corollary 3 says that we should not design one interface for each Service. Rather we can create one system, for example Enterprise Service Bus (ESB, Figure 8a) to integrate these different Services to fulfill a variety of business goals. Corollary 4 states a well-known design rule: use standard parts. Corollary 4 implies that we should use standard parts, processes, devices, systems, or architectures in the design. Corollary 4 is the theoretical foundation for achieving interoperability or plug-and-play in designing any integrated adaptive systems. In fact, SOA and DODAF, which are standard architectures for designing integrated SOS, are examples of Corollary 4. In Theorem M2, we represent a large organization as systems-of-systems, such as the C4ISR. Each subunit represents the individual subsystems, for example a logistical node, or a soldier on the battlefield. Because in adaptive SOS, each subunit operates autonomously to achieve its own local objectives, it must choose to satisfy some independent subsets of the global objectives at its local level. Consider the warfighter in the C4ISR ecosystem. The soldier sees a narrow view of the entire C4ISR. The warfighter cannot directly meet the global objectives of the C4ISR. Therefore, to achieve the overall goals of the C4ISR, the soldier must perform the battlefield activities whose local performance measures must still support the global performance measures (overall mission objectives). Theorem M2 establishes the command intent -- vision and mission statements -- for a large-scale distributed enterprise system. In fact, it establishes the unity of purpose for the civil military-complex endeavor, espoused by Alberts et al. [Alberts et al. 2007] – for designing an integrated complex systems-of-systems in complex dynamic environment involving many different partners such as civil authorities, multinational and international organizations, non-governmental organizations (NGOs), companies, and private volunteer organizations such as in Tsunami and Katrina.

Designing an integrated, C4ISR SOS, is extremely challenging. The issue of coupling of OV-5s with OV-1 and the stove-piped SOS in DODAF, which Nyamekye found in his recent work, must be addressed before using the (SOA)-Based DODAF. Currently, DODAF says that for any new Operational Activity models, OV-5s, that we define for creating new Net-Centric Services, we must also create an associated OV-1. In SOA, we can mix and match OV-5s to create new Services (new OV-5s) to achieve new mission capability. In fact mixing and matching OV-5s to create new OV-5s for achieving agility of integrated systems-of-system, is the hallmark of SOA. This implies that the old OV-1s would have to change to match the new OV-5s. This is not a good design. In fact, such a systems-of-systems design violates AXIOM 1, and it increases the information content, AXIOM 2 of the Net-Centric SOS design – too many OV-1s that are hard to keep track of. Thus, when we say coupling of OV-5s with OV-1 we mean that when we mix and mach the old OV-5s to create new OV-5s, we must change the old OV-1s. Thus, the new OV-5s would cause the old the OV-1s to change, and this in turn would create many stove-piped systems. The new DODAF, which Nyamekye coins it as (SOA)-Based DODAF, also recognizes that unless a governance model, Corollary 4, is used for achieving standardization in designing the Net-Centric Services, stove-piped systems are paramount to occur even with the (SOA)-Based DODAF. However, the new DODAF does not show the scientific concept for eliminating stove-piped systems.

© Copyright Integrated Activity-Based Simulation Research, Inc. 2008

Figure 8b, shows the SOA model adapted from Nyamekye's work and Figure 9 the DODAF data elements. Figure 10 shows the explanation of the DODAF data elements, in Figure 9. For more details about DODAF and SOA, please see Nyamekye's recent work [Nyamekye June 2007]. We will borrow the two-step solution proposed by Nyamekye to address the issue of coupling of OV-5s with OV-1 and the stove-piped SOS with DODAF.

First, we should create one generic value chain model, similar in concept to Porter's generic value chain model (Figure 11) for creating any DOD enterprise value system. Porter's generic value chain model stems from the strategic management science. Because the generic value model applies to any enterprise, we can say that it is an example of Corollary 4. Please note that integrated value chains, creates the Porter's value system, Figure 12. The value chain model does not change even when new Operational Activity Models (OV-5 in Figure 10) are introduced into the SOA model. In fact, the SOA model is independent of any particular business process or an activity. Figure 13 shows the value chain model, which Nyamekye proposed in his work. Please note that the generic value chain conceptual model, Figure 13, associates with the DOD enterprise level processes and activities (not shown) in the Mission Capability Package (MCP) value view model, Figure 14, and the business process layer in the SOA conceptual model, Figure 8, respectively. Please also note that Nyamekye's value chain model (Figure 13) is similar in concept to the conceptual model of the DODAF acquisition process as it relates to the architecture-based analysis of integrated DOD SOS, Figure 15.

Consider "Create the enterprise", in Figure 13. It involves all the activities associated with prototype modeling and simulation of the entire value system and must completely model all the subsequent stages of the integrated SOS. "Create the enterprise" is also equivalent to the "Concept Refinement', "Technology Development", and "System Development & Demonstration", in Figure 15. Similarly, "Achieve operational excellent", in Figure 13, is equivalent to the "Production & Deployment", in Figure 15. "Provide superior customer service…" in Figure 13, is equivalent to the "Operations & Support", in Figure 15. Figure 15 does not have "Dispose intangible assets…" When we use such a generic value chain model to design the DOD enterprise value system, the High-Level Operational Graphic Model (OV-1 in Figure 10) that describes the specific war-fighting and business processes, now becomes a sub-layer of the generic value chain model. In fact, the meaning of OV-1 becomes less relevant because the OV-5 can also be obtained directly from the appropriate generic processes in the generic value chain model, such as in Figure 16 (from Porter's model). The OV-1 would only be useful for the visual display of the business processes, high-level warfighter operations and assets, and perhaps for showing the metadata of the specific processes used for constructing the operational nodes and thus the Operational Node Connectivity Description (OV-2). We will discuss operational nodes later. Thus, OV-5 can be changed without changing the generic value chain model because the generic value chain model shows only the generic names for processes, e.g., customer service or operations and support. In addition, we do not need to change OV-1s to match new OV-5s. Consequently, no coupling of OV-5s with OV-1s will occur with this approach.

Figure 17a shows an example of OV-1 that can be a sub-layer of processes and operational activities associated with Stages 2 and 3 of Figure 13. Porter shows a similar concept in Figure 16. In Figure 16 the sub-layer of the generic value chain, shows the specific details of the business operations in the generic value chain. Please notice that the DOD business operations in Figure 17a also appear in Porter's generic value chain, Figures 11, and 16 [Porter 1985]. *Budget Planning* is an example of a *firm infrastructure's* activity in Porter's value chain model; *Engineering Analysis & Approval* is also an example of *technology development's* activity in Porter's value chain model. Figure 17b shows a new OV-1 template, which can serve as a generic model for designing any DOD mission plan and Net-Centric SOS.

Secondly, to eliminate stove-piped systems, we will borrow again from Nyamekye's work [Nyamekye June 2007]. We will first use Corollary 4 as the scientific basis for SOA Governance to achieve standardization of Net-Centric Services for the C4ISR SOS. This implies that any Services registered with the Net-Centric value systems-of-systems must not have any redundancies across the entire Net-Centric ecosystem. Furthermore, they must have the same names across the entire value system. They must be exposed to the ecosystem using the standard protocols for the SOA, to enable the appropriate level and quality of communication, information exchange, and collaboration required for success among the

© Copyright Integrated Activity-Based Simulation Research, Inc. 2008

different entities in the C4ISR. We should emphasize that process standardization or standardized choreographed Services, is one of the fundamental scientific issues in designing Integrated Manufacturing Production Systems (IMPSs) [Nyamekye et al. 2005; Black 1991; Monden 1983]. It has been one of the major scientific reasons for Toyota and Wal-Mart to achieve superior integrated adaptive supply chains. With process standardization through Corollary 4 (Use of Standardization), the C4ISR entities can scale up to include the Services of Communities of Interests (COIs) without creating any stove-piped systems.

According to DODAF [DODAF Version 1, Deskbook February 2004], Figure 9, OV-5 is the basic building block for designing any integrated SOS, after Overview and Summary Information (AV-1), the Integrated Dictionary (AV-2), and the OV-1 products have been constructed. The DODAF's Deskbook, that provides the guidelines and a suggested build sequence for developing data-centric architecture products (Figure 9), puts it this way [DODAF Version 1, Deskbook February 2004]: *"To a very large extent, **OV-5** provides the foundation for the remaining OV products."* The DOD's thinking here is that it is the mixing and matching of appropriate operational activities, the selection of appropriate resources to execute the activities, the skill set for the activities, network configurations, and so on, that determine the success of any given mission associated with a particular Mission Capability Package (MCP). Once the OV-5 has been designed, the operational nodes, defined as the logical groupings of operational activities to carry out the operational concept (OV-1) – warfighter operations or the business operations—can now be created. When we add needlines between the operational nodes, we can create the Operational Node Connectivity Description (OV-2), Figure 9. A needline documents the requirement to exchange information between any pair of nodes [DODAF Version 1, Deskbook February 2004]. We should emphasize again that the idea of using the OV-1 as the basis to describe the OV-5 for constructing the operational nodes is not an encouraging idea. The primary reason is that such an idea tends to create clusters of departmentalized processes or operational activities rather than creating enterprise level logical groupings of processes or operational activities. Enterprise level logical groupings of processes or operational activities are designed to be independent of any particular department in an enterprise [Martin Book II 1990]. Organizational changes are common in today's fierce competitive market. Thus, to adapt to the dynamic market conditions, an enterprise would redesign its organizational structure independently of the enterprise level logical groupings of processes or operational activities. The enterprise could even move non-mission critical logical operational activities to any location offshore where the enterprise could achieve the overall lowest cost, efficiency, and appropriate skill set. This issue has now become a major problem in designing SOA Services for an enterprise. Dejong [Dejong April 15 2007] calls the departmentalized Services the new applications silos for SOA. Figure 18 shows the conceptual model of Services as application silos (departmentalized Services), as envisioned by Dejong.

Using Theorem M2, we must then define the AV-1, the mission, and vision statements, that is, the command intent, for the entire C4ISR SOS. Using the new DOD generic enterprise value chain model and value system model proposed by Nyamekye, Figures 13a and 13b, and Corollary 4 (the governance model), we should define the DOD enterprise level business processes and warfighter processes. We then use the Cartesian Product (Cross Product) [Nyamekye June 2007] of databases and business/warfighter processes or operations to create process-subject data base matrix, and use Corollary 2 to eliminate any redundancies in processes, Figure 19. Please note that in Figure 13b, the arrows, from the warfighter value chains to the DOD value chains or to the suppliers' value chains, indicate return channels for decommissioned assets, such as damaged Humvees (HMMWVs) and Tanks by improvised explosive devices (IEDs). These assets must be returned for repairs or must be scrapped. Using the partitioning theory and Corollary 3, we partition the matrix into logical groupings of processes or natural subsystems, Figure 20. Again, we use the Cartesian Product (Cross Product) of entity types and business/warfighter operational activity models (OV-5s) to create the leaf activity-entity type matrix, Figure 21, and use Corollary 2 to again to eliminate any redundancies in operational activities. Using the partitioning theory again, we partition the leaf activities and entity types into logical groupings of operational leaf activities or operational nodes, Figure 22. We create the leaf services, Figure 23a, from the leaf activities, Figure 22.

Using the composition theory [Milner 2004; Van der Aalst et al. 2004; Girault et al. 2003], we compose the leaf services into composite services to create the operational activity models (business/warfighter

processes), OV-5s, Figure 23b, for the subsystems. The subsystems are the same as the operational activity nodes or operational nodes. Please note that when we add the needlines to the operational nodes, we get Operational Node Connectivity Description (OV-2). We repeat the same procedure to create the other subsystems. We then design the integrated subsystems, using Corollary 4 to achieve the configuration for SOA (SV-1, and SV-2). Figure 24 shows the (SOA)-Based DODAF C4ISR SOS, which is an updated version of the previous work by Nyamekye [Nyamekye June 2007]. An example of suppliers' value chains is Halliburton's food value chain to supply food for the warfighter. The Internet or the communications network is the network for the performance model, as noted before. Please note the similarities between Figure 24 and Figure 25, proposed by Alberts et al. as the SOA blueprint for Global Information Grid (GIG) user Services [Alberts et al. 2003]. However, Alberts et al. did not discuss the scientific approach for creating the systems-of-systems depicted in Figure 25.

INFORMATION CONTENT FOR NETWORK PERFORMANCE

We employ Equation 20 for the information content, AXIOM 2. The T_C, is the leaf FR (lowest FR). The input parameters, DPs, associated with the leaf FR, are namely: $\deg_z, \lambda_i, \gamma$, μ', F_i, μ, L_i, SP, $\deg_z$, and network classification – Regular, Random, etc. As noted before the classical optimization models do not achieve optimum results when several FRs must be optimized. Furthermore, the classical optimization techniques give single values rather than a range of values. Though, our focus here is on evaluating one performance measure, T_C, we could as well evaluate several performance measures and find the global optimum performance measure, from Equation 2. So, rather than discussing the generic approach for one FR, we will discuss the generic approach for several FRs. The data for DPs and FRs can come from simulation and modeling, or actual experimental work.

Using AXIOM 2, Nakazawa [Nakazawa 2001], has nicely discussed the approach for evaluating the minimum total information content for several FRs. He calls the overall design concept, Design Navigation Method. For convenience, we will use the symbols from his work. The steps are as follows.

In Figure 26, the A_S represent the DP, and the E, the FR. First we vary the design parameters to take on the values, $A1, A2, ...Ap$, each of which yields multiple (n) experimental or simulation data, on a given FR, E. These data will show a scattered distribution. For the (n) data points gathered for $A1$, the mean, m, and the standard deviation σ (square root of unbiased variance) are obtained. The two points, representing $m \pm k\sigma$, are then plotted above $A1$, as we can see in Figure 26. The k is the safety factor. The two points will correspond to the upper and lower limits of the system range. We then repeat the same method for the upper and lower limits for the rest of the parameter values, $A2$, ..., Ap. We then fit a line, a quadratic, or other curve through the points representing the upper limits, while those in the lower limits are fitted with another curve. We can now enter the design range [discussed earlier in Equation 1], Ed for the upper value and the lower value, on the same graph, as we can see in Figure 26. We can now establish the common range [discussed earlier in Equation 1] for any design parameter value between $A1$ and Ap. Using Equation 1, we find the information content (function error) for each design parameter value, between $A1$ and Ap. For example, at $A1$, we find the information content (function error). Similarly, we obtain the information content (function error) for $A2$ and Ap, respectively. We go through the entire steps again for the other functional requirements and sum up the information contents (function errors) at each parameter value; plot the information content (function error) values as a function of the design parameter values on a graph, to obtain the total information content (total function error). Figure 27 exhibits the total information content (total function error, Equation 2). Please note that the minimum total information content (total function error) value occurs at Aop. However, within $A1$ and Ap, the total information content (total function error) is acceptable.

© Copyright Integrated Activity-Based Simulation Research, Inc. 2008

Nakazawa has shown such steps for many design parameters (especially when the design parameters exhibit interaction effects as in typical in experimental designs) and many functional requirements. For convenience, we will omit the details of the discussion and refer the reader to the Nakazawa [Nakazawa 2001]. We will show only the graphs for the case when two design parameters, A and B are involved. Figure 28 shows the graph of experimental or simulation data for the functional requirement E with interaction factors among the design parameters. Figure 29 shows the information content (function error), when interaction effects exist between the design parameters A and B at various levels in the range $A1$ and $A2$, of the parameters, respectively. The function error disappears in the range between $A3$ and $A4$ (Figure 29b), where the functional requirement for item E is satisfied for any value of design parameter B. Thus, we can choose any value in between $A3$ and $A4$, independently of B. Nakazawa has use this Design Navigation Method quite extensively for many designs, including Computer Numerical Machine (CNC) machines, with remarkable results [Nakazawa 2001]. He suggests using an orthogonal table, such as in Table 1, to construct the experimental or simulation design.

SERVICE-BASED SIMULATION MODELS AND EXPERIMENTAL TESTS

Full-scale experimental tests for evaluating the network performance of integrated Service-based C4ISR systems, is very expensive. We will need to construct the entire ecosystem, within which the network is a subsystem. Especially for Net-Centric SOS, such an integrated SOS may include several hundred entities, such as coalition partners and other NGOs. More importantly, the SOA is itself is a new concept, and many enterprises are still struggling to even understand the concept and let alone even build the Service-based test bed [eWeek June/July 2006]. Thus, even creating an experimental test bed, still presents significant challenges. Kleinrock has done a remarkable job in pointing out the difficulties his research team encountered during actual experimental studies of the ARPANET, which was on a global scale. Thus, our approach to network performance analysis is to construct the Service-based modeling and simulation, before building a prototype. The design loop proposed by Wilson, Figure 3, also emphasizes such an idea.

Much literature exists on simulation methodologies. However, most tend to be discrete event simulation, with very little humanization of the entities to capture the cognitive and social behaviors of the entities within an ecosystem. Consider Toyota's example of self-synchronization of the agents (workers) on the factory floor in emergencies. The agent must draw on his or her cognitive capability, by first processing the information, that something has happened to the machine, and that without properly understanding the problem he or she cannot resolve it alone. When he or she sees that problem is beyond his or her control, the agent relies on information network by activating the andon light that broadcasts the problem to other colleagues on the factory floor. The other workers, also understanding that they must rescue the troubled worker for the ecosystem to function properly, rush to collaboratively assist the co-worker. Current discrete event simulations cannot capture such cognitive and social behaviors of the workers on the factor floor and let alone on the battlefield where the dynamics of the battlefield can change much more rapidly. We suggest using the organizational simulation concepts, proposed by Rouse et al. [Rouse et al. 2005]. One view of using organizational simulation is the "virtual world" view. In the "virtual world", the simulation user has an immersive experience of the organizational simulation using some type of virtual realty technology [Mcginnis 2005]. According to Mcginnis, a lower-resolution version of such user's experience would be similar to that of the popular interactive games such as EverQuest [Sony 2004] or Half-Life [Sierra 2004]. He emphasizes that in either case, visual rendering of the organization, through which the user experiences and interacts with the results of the simulation, exists. We suggest using Meta-Model approach [Ledeczi et al., Rouse et al. 2005] to represent and simulate organizational entities and the relationships among the entities for the Service-based C4ISR SOS. Nyamekye has currently envisioned such an approach [Nyamekye January 2008]. Using the Generic Modeling Environment (GME, [GME]) created by the Vanderbilt University and sponsored by the Boeing Company and Defense Advanced Research Projects Agency (DARPA) for designing any distributed enterprise systems-of-systems, we can first create a Service-based abstract or meta-model of an ecosystem involving the warfighters and the adversaries in the C4ISR SOS. The Service-based model then becomes the basis for a conceptual training-based distributed systems-of-systems model, which could be instantiated for any specific asymmetric or symmetric simulation-based training system. From the service- based model, we

© Copyright Integrated Activity-Based Simulation Research, Inc. 2008

can use intelligent distributed multi-agent-based system to create symmetric or asymmetric threat tactics; generate behavior in a simulation-based training environment; and study the effect of information overload on the network infrastructure (Equation 20), and the cognitive and social behaviors of the friendly adversary and the foes. Using Equation 20 and Design Navigation Method, we can predict the network performance. We suggest using Table 1 to create the design of experiment for the simulation runs. To create an adaptive network, we can use Corollary 1, and the multi-agent agent system to dynamically adjust the network to respond to uncertainties due to information overload. Using Corollary 1 to design intelligent decouplers [Black 1991, Nyamekye 2005] that can provide extra bandwidths in the network, will reduce information overload, and thus permit the network to dynamically adjust itself to uncertainties.

CONCLUSIONS

The paper has discussed information content for adaptive network performance for C4ISR systems-of-systems using queuing theory and axiomatic design approach. Recent work by National Research Council (NRC) concludes that network research is an emerging scientific field. In fact, the definition of the technical terms for the network science is still unclear. Compounding this issue is the fact that the fundamental knowledge of networks is still primitive. Thus, the paper first summarizes the network types, network classifications, and the properties of network. Drawing on the previous author's work, the paper emphasizes that the axiomatic design, integrated with Service-Oriented Architecture-Based Department of Defense Architecture Framework (SOA)-Based DODAF, establishes the scientific framework for designing integrated C4ISR systems-of-systems (SOS), of which the network infrastructure is a subsystem. Borrowing Kleinrock's work on ARPANET, the detailed queuing models have been presented for the network performance. Furthermore, the information content from AXIOM 2 of axiomatic design is employed for the network optimization, including the effect of information overload, on the network performance for the Net-Centric SOS. The paper discusses that the Service-based simulation and experimental tests are needed to provide the data for the queuing models for network performance and optimization of the C4ISR SOS. The Design Navigation Method, proposed by Nakazawa has been discussed for experimental and simulation design, and for optimization, under scenarios of multi-functional requirements (FRs) and interaction effects among the design parameters (DPs). Using Corollary 1 to design intelligent decouplers that can provide extra bandwidths in the network, will reduce information overload, and thus permit the network to dynamically adjust itself to uncertainties. Such an integrated queuing modeling and axiomatic design approach, is critical for not only designing and operating complex civil-military endeavors, but also it is critical for creating a test bed for designing information-based distributed enterprise systems for counter-terrorism and natural disasters such as Katrina for the Department of Homeland Security.

REFERENCES

Alberts, S.D., and R. E. Hayes, "PLANNING: COMPLEX ENDEAVORS," CCRP Publication Series, April 2007.

Alberts, S.D., and R. E. Hayes, "THE FUTURE OF COMMAND AND CONTROL: UNDERSTANDING COMMAND AND CONTROL," CCRP Publication Series, 2006.

Alberts, S.D., and R. E. Hayes, "Power to the Edge," CCRP Publication Series, 2003.

Alberts, S.D., J. J. Gartksa, and P., Stein, and P. F., NETWORK CENTRIC WARFARE: Developing and Leveraging Information Superiority, 2nd Edition (Revised), CCRP Publication Series, 1999.

Anthes, G., "Q&A: An Internet Pioneer Looks Ahead," http://computerworld.com/printthis/2005/0,4814,102862,00.html, COMPUTERWORLD, July 4, 2005.

Arsanjani, A., "Service-Oriented Modeling And Architecture: How To Identify, Specify, And Realize Services For Your SOA, Level: Intermediate," IBM DeveloperWorks, November 9, 2004.

Atkinson, R. N., and Moffat, J., "The Agile Organization: From Informal Networks To Complex Effects and Agility," CCRP Publication Series, 2005.

Black, J T., THE DESIGN OF THE FACTORY WITH A FUTURE, McGraw-Hill, Inc., New York, NY, 1991.

Bloomberg, J., and Schmelzer, R., Service Orient or Be Doomed: How Service Orientation Will Change Your Business, John Wiley & Sons, Hoboken, NJ, March 2006.
Bowen, K. C., "Research Games – An Approach the Study of the Decision Processes," Taylor and Francis, UK, 1978.
Bradley, P. S., and R. L., Sense & Respond: Capturing Value in the Network Era, Harvard Business School Press, Boston, MA, 1998.
Brooks, R., "Newer Math? A New High-School Mathematics Might Someday Model Complex Adaptive Systems," Technology Review: AN MIT ENTERPRISE, http://www.technologyreview.com//wtr_16010,1,p1.html, December 2005/January 2006.
Chang K., H., and Nyamekye, K., "Distributed Intelligent Control Systems for an Unmanned Manufacturing Cell," Expert Systems in Engineering Systems, Chapter 19, pp. 353-364, Spyros Tzafestas, Editor, Spring-Verlag, New York, NY, 1993.
Cohen, D., "All the World's a Net," New Scientist, pp. 24-29, April 13, 2002.
Defense Electronic Business (DEB), *Joint Electronic Commerce Architecture*, 2000.
Dejong, "Will SOA Become the New Siloed Appl?" http://www.sdtimes.com/download/index.html, SD TIMES, APRIL 15, 2007; ISSUE NO. 172.
DODAF (DOD Architecture Framework), Version 1: Deskbook, February 9, 2004.
DODAF (DOD Architecture Framework), Version 1, Volume I: Definitions and Guidelines, February 9, 2004.
DODAF (DOD Architecture Framework), Version 1, Volume II: Product Descriptions, February 9, 2004.
DODAF (DOD Architecture Framework), Version 1.5, Volume I: Definitions and Guidelines, April 23, 2007.
DODAF (DOD Architecture Framework), Version 1.5, Volume II: Product Descriptions, April 23, 2007.
DODAF (DOD Architecture Framework), Version 1.5, Volume III: Architecture Data Descriptions, April 23, 2007.
Eisenstadt, M., "Tribal Engagement Lessons Learned," Military Review http://usacac.army.mil/CAC/milreview/English/SepOct07/eisenstadtengseptoct07.pdf, September-October, 2007.
eWeek, "By the Numbers SOA what," June 26/July 3, 2006.
Emery, D., LTC D. Bassett, LTC M. Schnaidt, "The Net-Centric Foxhole," Perspectives From Army Future Combat Systems, 2006 Systems, http://www.dtic.mil/ndia/2006systems/Wednesday/emery.pdf, October 25, 2006.
Handfield, B. R., and E. L. Nichols, Jr., Supply Chain Redesign: Transforming Supply Chains into Integrated Value Systems, Prentice Hall, Upper Saddle River, NJ, 2002.
Hammer, M., and J., Champy, Reengineering the Corporation, HarperBusiness, Revised Edition, New York, NY 1022, 2001.
Havey, M., Essential Business Process Modeling, O'REILLY Media, Inc, Massachusetts, 2005.

Hillier S. F., and Lieberman J. G., Introduction To Operations Research, 7th Edition, McGraw-Hill, New York, NY. 2001.
Jones, V. C. MAO/TOP Networking: A Foundation for Computer-Integrated Manufacturing, McGraw-Hill, New York, NY, 1988.
Kleinrock, L., Computer Applications, Volume II: Queuing Systems, John Wiley & sons, New York, NY 1975.
Knowledge Wharton, Leadership and Change, "Tip of the Spear: Leadership Lessons from the U.S.-led Armed Forces in the Middle East," http://knowledge.wharton.upenn.edu/index.cfm?fa=viewfeature&id=1484, Knowledge Wharton, May 17, 2006.
Krone, R., "Managing a Complex System-of-Systems," http://govinfo.library.unt.edu/moontomars/docs/050404SlidesKrone.pdf, White Paper, The Boeing Company, May 4, 2004.
Ledeczi, A., Maroti, M., Bakay, A., Karsai, G., Garrett, J., Thomason, C., Nordstrom, G., Sprinkle, J., and Volgyesi, P., "The Generic Modeling Environment," White Paper, Vanderbilt University, Institute for Software Integrated Systems, Nashville, TN 37235, USA.

Lublinsky, O., "Defining SOA as an architectural style: Align your business model with technology, Level: Intermediate," IBM DeveloperWorks, January 9, 2007.
Marx, M., "Six Sigma at the Army Reserve's 96th Regional Readiness Command," http://www.sixsigmacompanies.com/archive/six_sigma_at_the_army_reserves_96th_regional_readiness_command.html, May 9, 2006.
Martin, J., Information Engineering, Book I: Introduction, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1989.
Martin, J., Information Engineering, Book II: Planning and Analysis, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1990.
Martin, J., Information Engineering, Book III: Design and Construction, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1990.
Mcginnis, L. F., Technical And Conceptual Challenges In Organizational Simulation, John Wiley & Science, Inc., Hoboken, New Jersey, 2005.
McLean, C., and Riddick, "THE IMS MISSION ARCHITECTURE FOR DISTRIBUTED MANUFACTURING SIMULATION," Winter Simulation Conference 2000, http://www.mel.nist.gov/msidlibrary/doc/WSC2000.pdf, 2000.
Milgram, Stanley. "The small world problem." Psychology Today. Vol 2. 1967. pp. 60-67.
Milner R., Communicating and Mobile Systems: the Pi-Calculus, Cambridge University Press, 2004.
Moffat, J., "Complex Theory and Network Centric Warfare," CCRP Publication Series, 2003.
Moffat, J., "Command and Control in the Information Age: Representing its Impact," The Stationery Office. London, UK, 2002.
Monden, Y., Toyota Production System: Practical Approach to Production Management, IIE Press, 1983.
Murch, R, Autonomic Computing: On Demand Series, Prentice Hall, Upper Saddle River, NJ 07458, 2004.
Nakazawa, H., and N. P. Suh, "Process Planning Based on Information Concept," Robotics and Computer Integrated Manufacturing, Vol. 1, No. 1, pp. 115-123, 1984.
Nakazawa, H., "Product Design Development by Design Navigation Method," JSME International Journal, Series C, Mechanical Systems, Machine elements and Manufacturing 2001, vol. 44, n3, pp. 848-855.
National Research Council, Surviving Supply Chain Integration: Strategies for Small Manufacturers, National Academy Press, Washington, D.C., 2000.
National Research Council, Modeling and Simulation in Manufacturing and Defense Acquisition: Pathways to Success, National Academy Press, Washington, DC, 2002.
National Research Council, Network Science, National Academy Press, Washington, DC, 2005.
NATO SAS-050, "Exploring New Command and Control Concepts and Capabilities," Final Report, Prepared for NATO, January 2006.
Net-Centric Checklist, Office of the Assistant Secretary of Defense for Networks and Information Integration/Department of Defense Chief Information Officer, http://www.dod.mil/cio-nii/docs/NetCentric_Checklist_v2-1-3_.pdf, Version 2.1.3, May 12, 2004.
Nissen, Mark E., "Enterprise Command, Control, and Design: Bridging C2 Practice and CT Research," The International C2 Journal, Volume 1, Number 1, 2007.
Nott, C., and Stockton, M., "Choose an ESB Topology to Fit Your Business Model: Level Introduction," http://www-128.ibm.com/developerworks/library/ws-soa-esbtop/, March 15, 2006.
Nyamekye, K., J. A. Clendenin, and H. Burleson, "Information System Architecture for Wired Battlefield," 2004 Proceedings of Navy Marine Corps Intranet, June 2004 [CD Version].
Nyamekye, K., "Supply Chain Design for Six Sigma (DFSS): an Axiomatic Quality Approach, " American Society for Quality 2006 Six Sigma Conference Proceedings, Palm Springs, CA February 6-7, 2006.
Nyamekye, K., and J., A, Clendenin, "ICLOGISTICS JOINT BATTLESPACE INFOSPHERE (JBI)-GRID ARCHITECTURE, White Paper, July 2006.
Nyamekye, K., and Y.-K. An, "Using Rapid Modeling Technology in a Permanent Mold Casting Production Facility," AFS Transactions, Volume 96, pp. 96-188, 1996.
Nyamekye, K., "New Tool for Business Process Reengineering: Activity-Based Simulation Offers Functionality that We've Never Experienced Before Until Now," IIE SOLUTIONS, March 2000, pp. 36-41, http://findarticles.com/p/articles/mi_hb3002/is_200003/ai_n7865133.
Nyamekye, K., Sutterfield, S., Askeland, D. R., and Bain, R., and Cunningham, M.,

Classification and Coding: The First Step In Designing Manufacturing Cells: An article from: Modern Casting [HTML] (Digital), November 1994, Reprinted and Published, by Amazon Dot Com, http://www.amazon.com/gp/product/B00092YG9A/ref=sr_11_1/104-7516179-4397551?ie=UTF8, July 28, 2005.

Nyamekye, K., "Axiomatic Design Approach for Designing Re-Configurable C4ISR Systems," Proceedings of 12th ICCRTS: C2 TECHNOLOGIES & SYSTEMS, Paper Number I-220, http://www.dodccrp.org/events/12th_ICCRTS/CD/iccrts_main.html, June 2007.

Nyamekye, K., "Designing Integrated Intelligent Service-Oriented Architecture-Based Department Of Defense Architecture Framework Training System For Asymmetric Warfare," White Paper, January 3, 2008.

Ohno, T., "Toyota Production System: Beyond Large-Scale Production," Productivity Press, New York, NY, 1988.

Owen, D., and Eugene K. H., "Southeast Asia Tsunami Research Project." Report commissioned by the CCRP and prepared by Evidence Based Research, Inc. 2005.

Perry, W., Button, R. W. et al., "Measures of Effectiveness for the Information-Age Navy: The Effects of Network-Centric Operations on Combat Outcomes," RAND, Santa Monica, CA, USA, 2002.

Porter Michael E., Competitive Advantage: Creating and Sustaining Superior Performance: With a New Introduction, The Free Press, A Division of Simon & Schuster Inc., New York NY, 1985.

Ricks, Thomas E. *Fiasco: The American Military Adventure in Iraq* (New York: Penguin Press HC, 2006).

Ricks, Thomas E. "The Counterinsurgency," *Washington Post*, February 16, 2006. http://www.washingtonpost.com/wp-dyn/content/article/2006/02/15/AR2006021502586_pf.html.

Roberts, P. F., "BT Nearing End Of SOA Project: Aiming For 2009 Completion Date," InfoWorld (US), http://www.techworld.com/applications/news/index.cfm?newsID=8860&pagtype=all, May 17, 2007.

Ross, W. J., P. Weill, and D. C. Robertson, Enterprise Architecture as Strategy: Creating a Foundation For Business Execution, Harvard Business School Press, Boston, MA, 2006.

Rouse B. W., and K. R. Boff, Organizational Simulation, John Wiley & Science, Inc., Hoboken, New Jersey, 2005.

SAP, "Building the Lean Extended Enterprise through Adaptive Supply Chain Networks: CEO Breakthrough! Special Research Report!" KNOWLEDGE STORM, February 9, 2007.

SCOR Version 7 Overview, Supply chain Operations Reference-Model, Supply chain Council.

Shannon, C. E., and Weaver, W., "The Mathematical Theory of Communication," University of Illinois Press, Urbana Press, Urbana, IL, 1949.

Schmelzer, R., "The State of Worldwide SOA Adoption: Is the US Behind?" http://www.zapthink.com/report.html?id=ZAPFLASH-200721, ZapThink, February 1, 2007.

Schmelzer, R., "SOA Infrastructure Patterns and the Intermediary Approach," http://www.zapthink.com/report.html?id=ZAPFLASH-200774, July 4, 2007.

Sierra, Half–Life, http://games.sierra.com/games/halg-life/.

Sony Online Entertainment, EverQuest, http://everquest.station.sony.com/.

Steckler, B., "NPS IT Fly-in Team Reconnects Tsunami Survivors to the World." Naval Postgraduate School. February 9, 2005.

Suh, N. P., The Principles of Design, Oxford University Press, New York, 1990.

Suh, N. P., Axiomatic design: Advances and Applications, Oxford University Press, New York, 2001.

Tofts, C.M.N., "Describing Social Insect Behaviour Using Process Algebra," Transactions of the Society For Computer Simulation, pp. 227-283, 1992.

TRADOC, http://www.tradoc.army.mil/tpubs/pams/p525-66.pdf.

Van Der Aalst, W., and Hee, V., WORKFLOW MANAGEMENT, The MIT Press, Cambridge, MA, 2004.

Vernadat, F. B., Enterprise Modeling and Integration: Principles and Application, Berlin: Chapman and Hall, 1996.

Weiss, G. Multi-agent Systems: A Modern Approach to Distributed Artificial Intelligence, The MIT Press, Cambridge, MA, 1999.

Wilson, D. R., "An Exploratory Study of Complexity in Axiomatic Design," Ph.D. Thesis, MIT, August, 1980.

Wisnosky, D., J. Vogel, and S. Ring, "The Road to Executable Architectures," http://www.wizdom.com/roadtoexecutablearch.ppt, November 2004.

Wooldridge, M., An Introduction to Multi-agent Systems, John Wiley & Sons, Hoboken, NJ, 2002.
Zachman J. A., "CONCEPTS OF THE FRAMEWORK FOR ENTERPRISE ARCHITECTURE," Zachman International, Inc., La Cañada, Ca., 1997.
Zimmermann, O., and M., Tomlinson, "Building Service-Oriented Architectures With Web Services: Extracts from Perspectives on Web Services – Applying SOAP, UDDI and WSDL to Real-World Projects," OOPSLA, 2005.
Zimmermann, O., P. Krogdahl, and C. Gee, "Elements Of Service-Oriented Analysis And Design: An Interdisciplinary Modeling Approach For SOA Projects, Intermediate Level," IBM DeveloperWorks, June 2, 2004.
Zimmermann, O., M., Tomlinson, and S. Peuser, Perspectives on Web Services – Applying SOAP, UDDI And WSDL to Real-World Projects; Springer, 2nd Edition, New York, NY, 2005.

BIOGRAPHICAL SKETCH OF THE AUTHOR

Dr Kofi Nyamekye is the author of this report. He is the founder, President and Chief Executive Officer of Integrated Activity-Based Simulation Research, Incorporated, formerly known as Nyamekye Research & Consulting (NRC). Through his career, he has developed the educational, research and industrial experience to design and operate any manufacturing production system. As an educator (a former college professor) and a researcher, Dr. Nyamekye has published extensive articles on the design and operation of Cellular Manufacturing Production Systems and Simulation and Modeling of the Traditional Manufacturing Processes. Dr. Nyamekye has received many awards, among them the *1994 Educator of the Year Award from the St. Louis Society of Manufacturing Engineers Chapter 17 and the 1996 Best Paper Award selected by the Engineering Division of the American Foundrymen's Society*.

Under a large research grant from the U.S. Department of Energy, he pioneered a computer simulation model for the mold failure of the permanent mold casting process. The model will play an essential part as a federate in a distributed enterprise simulation model for automobile manufacturing supply chain federations.

Dr. Nyamekye is a member of the NIST's International Consortium of Research Scientists called the IMS MISSION. The goal of the MISSION is to integrate and utilize new, knowledge-aware, technologies of distributed persistent data management, as well as conventional methods and tools in various enterprise domains, to meet the needs of globally distributed modeling and simulation. Under a grant from NIST, Dr. Nyamekye has established the methodology for designing Activity-Based Simulation (ABS) System as a federate in the NIST distributed enterprise simulation model for the NIST IMS MISSION. The NIST federation uses the HLA RTI architecture. The ABS uses the entity relationship (E-R) modeling technique for designing an Activity-Based Costing model with input data from the simulation federates for supply chain optimization.

Recent emphasis on Activity-Based Methodology by MITRE and Lockheed-Martin, for service-based simulation of NCW [Wisnosky et al. November 2004], and previous emphasis on Activity-Based Simulation by the Defense and Modeling Simulation Office [DMSO, https://www.dmso.mil/public/resources/glossary/results?do=get&def=14], have made Activity-Based Simulation the essential concept for dynamic simulation and optimization of Service-Oriented Architecture (SOA). Dr. Nyamekye is a senior research scientist in modeling and simulation of *complex adaptive distributed enterprise systems* for a DOD prime contractor. Dr. Nyamekye has previously published with other investigators the concepts for designing information system architecture for the wired battlefield. He has also recently established the scientific base for designing re-configurable C4ISR SOS [***Nyamekye June 2007***, http://www.dodccrp.org/events/12th_ICCRTS/CD/iccrts_main.html, ***C2 Technologies & Systems, #220***].

Dr. Nyamekye is also a member of the NIST Simulation Standards Consortium, and American Society for Engineering Education (ASEE). He holds a PhD in Industrial Engineering from Pennsylvania State University, an MS in Mechanical Engineering from Pennsylvania State University, and a BS in Mechanical Engineering from the University of Wisconsin. He can be reached at kofinsoyameye@earthlink.net.

© Copyright Integrated Activity-Based Simulation Research, Inc. 2008

APPENDIX A: LIST OF FIGURES

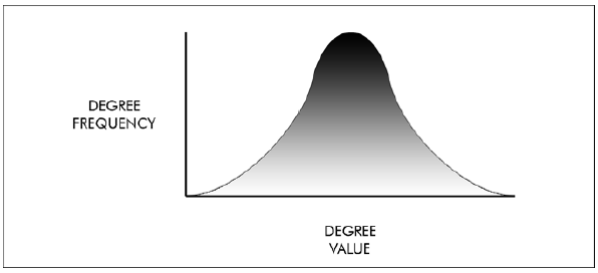


Figure 1. The Frequency Distribution of The Degree of A Random Network [Atkinson et al. 2005.]

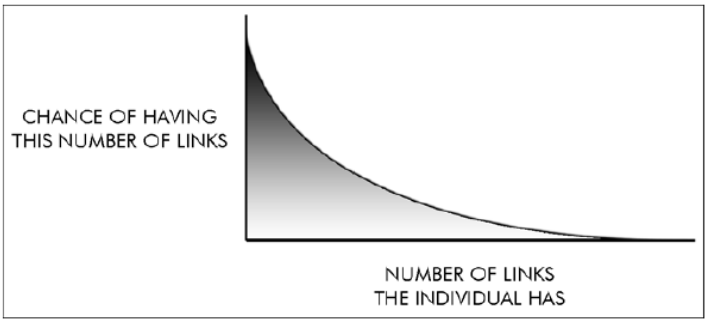


Figure 2. The Frequency Distribution of The Degree of A Scale-Free Network [Atkinson et al. 2005.]

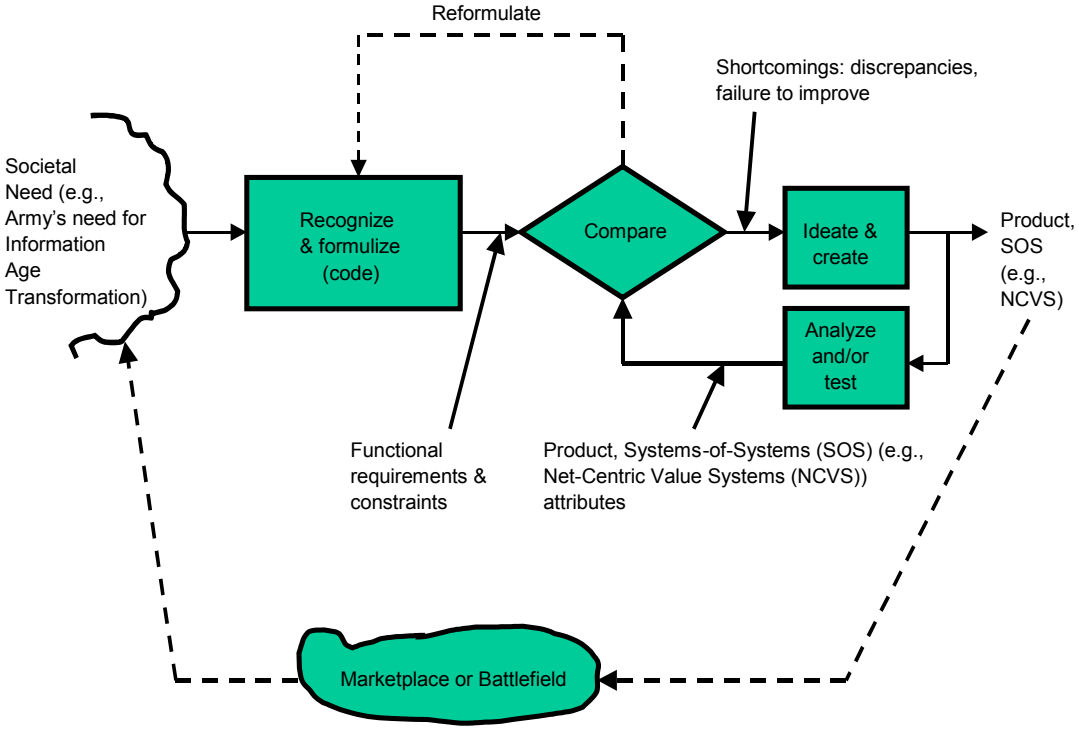


Figure 3. The Design Loop-As the Architecture for Systems-of-Systems (e.g., supply-chain, FCS) Design [Modified Version of Nyamekye et al., June 2005 (CD Version); Wilson, D. R., Ph.D. Thesis, MIT, August, 1980.]

© Copyright Integrated Activity-Based Simulation Research, Inc. 2008

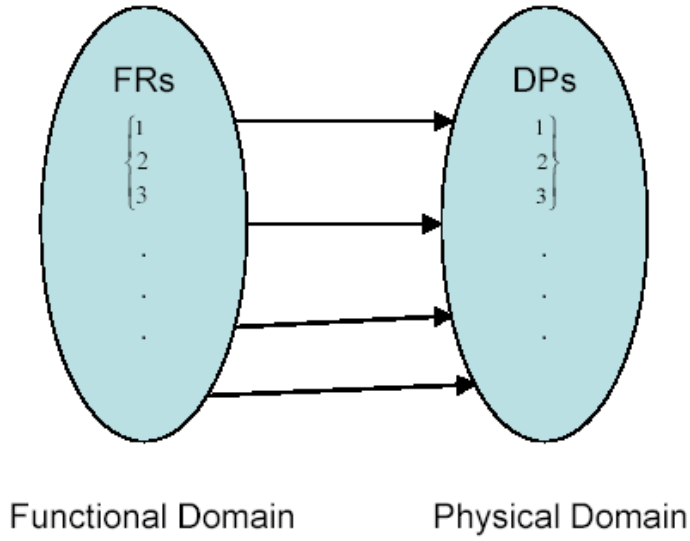


Figure 4. Mapping from the Functional Space (Or Domain) to the Physical Space (Or Domain), [Suh 1990.] The DPs in the physical space are chosen to satisfy the FRs in the functional domain.

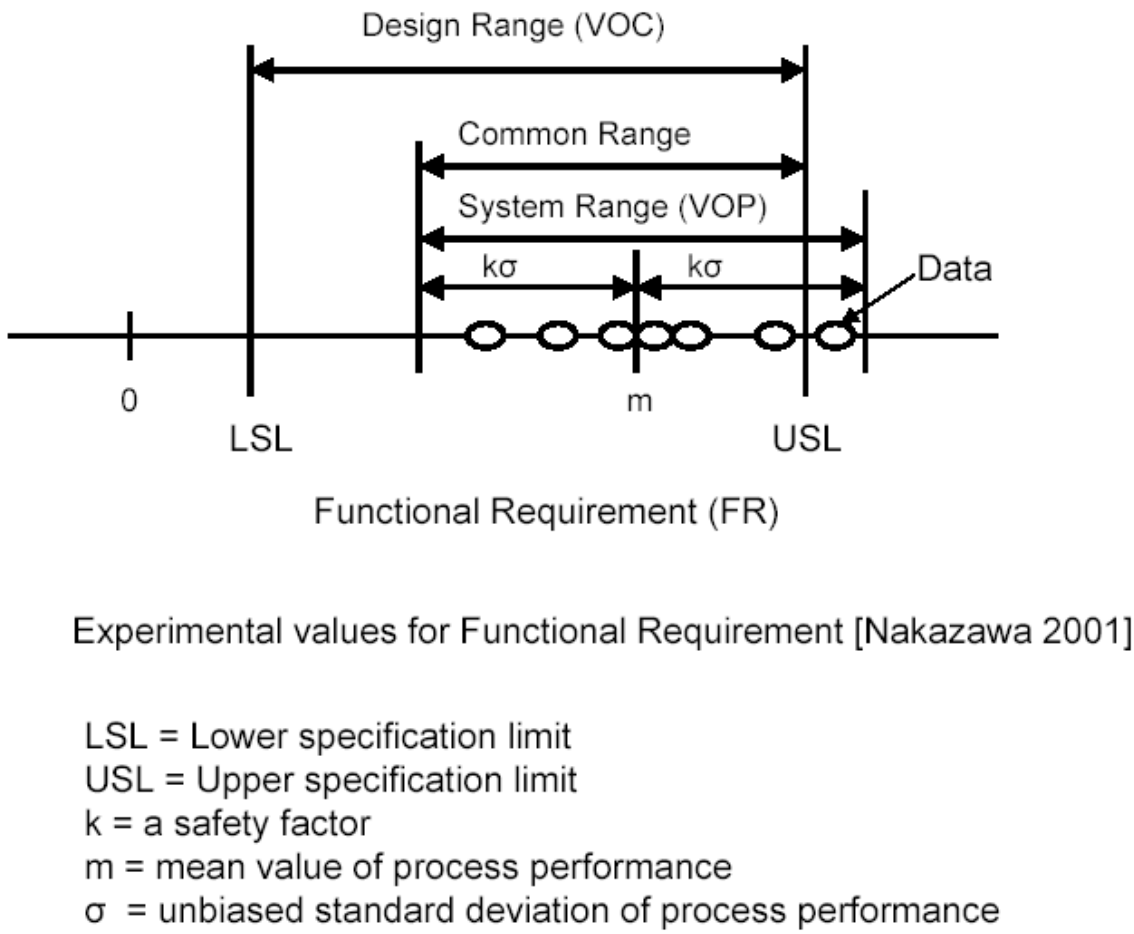
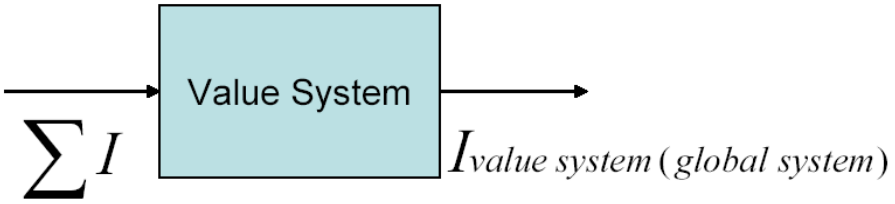


Figure 5. Illustration of Design Range and Common Range [Nakazawa 2001.]

© Copyright Integrated Activity-Based Simulation Research, Inc. 2008



I = Information Content (From AXIOM 2)
System Range = Voice of the Process (VOP)
Design Range = Voice of Customer (VOC)
Common Range = Amount of Overlap between VOC and VOP

Figure 6. Total Information Content, Equation 2.

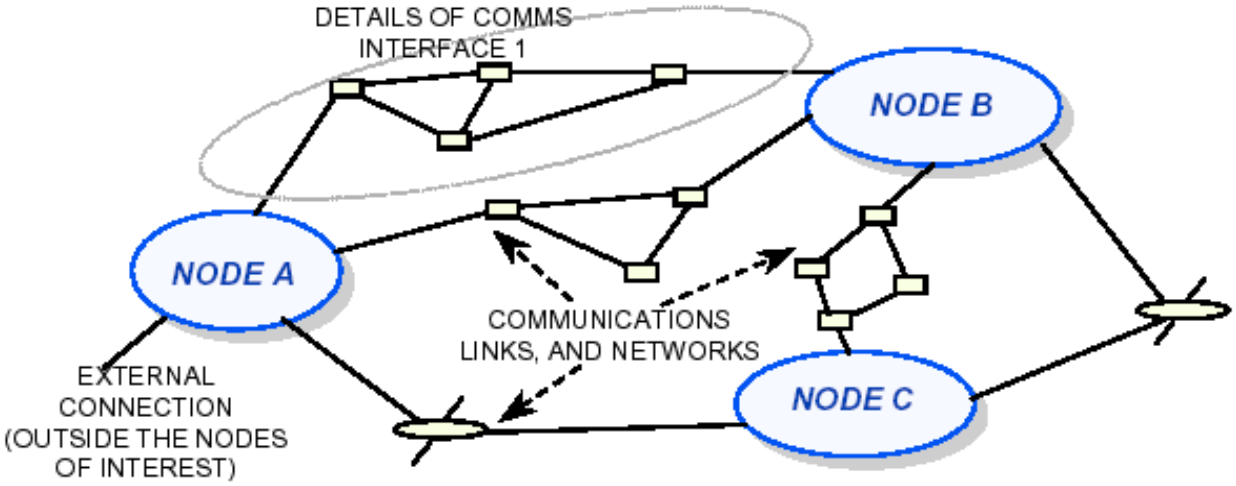


Figure 7. Systems Communications Description, Inter-nodal Version (SV-2) [DODAF Version 1.5, Volume II April 2007.]; Small boxes represent routers, and the oval shapes represent satellites.

© Copyright Integrated Activity-Based Simulation Research, Inc. 2008

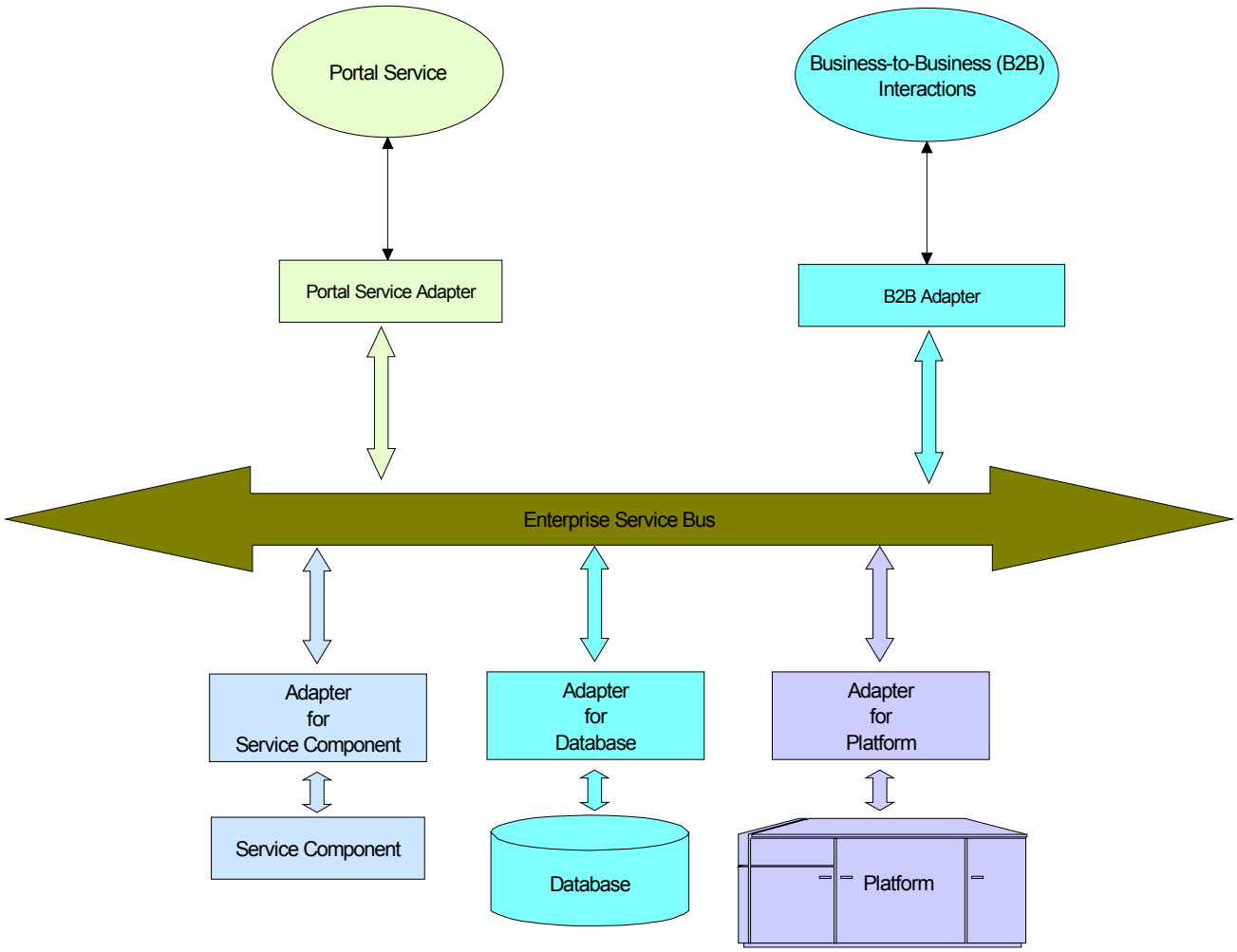


Figure 8a. Enterprise Service Bus [Nyamekye June 2007.]

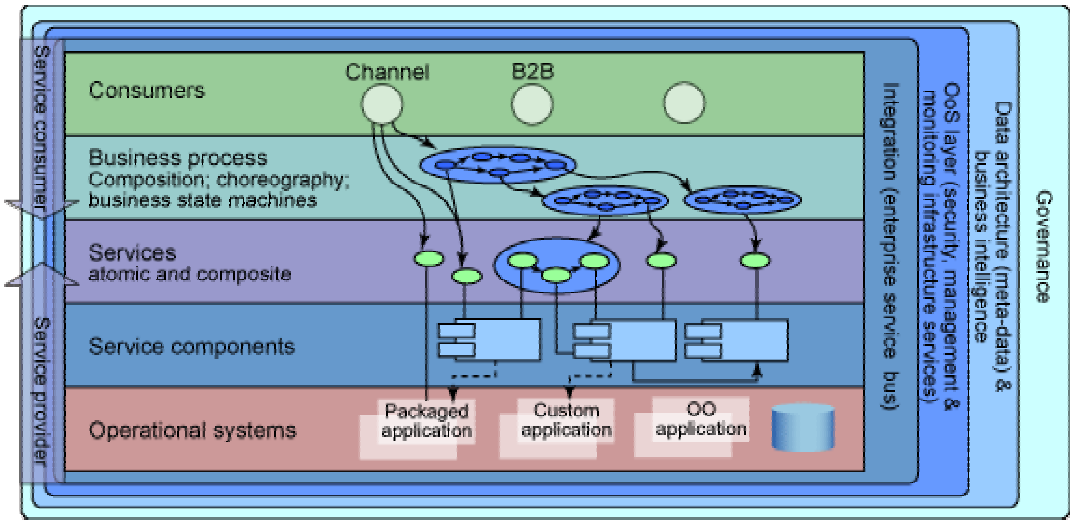


Figure 8b. The Different Layers of Service-Oriented Architecture (SOA) [Arsanjani November 9 2004.]

© Copyright Integrated Activity-Based Simulation Research, Inc. 2008

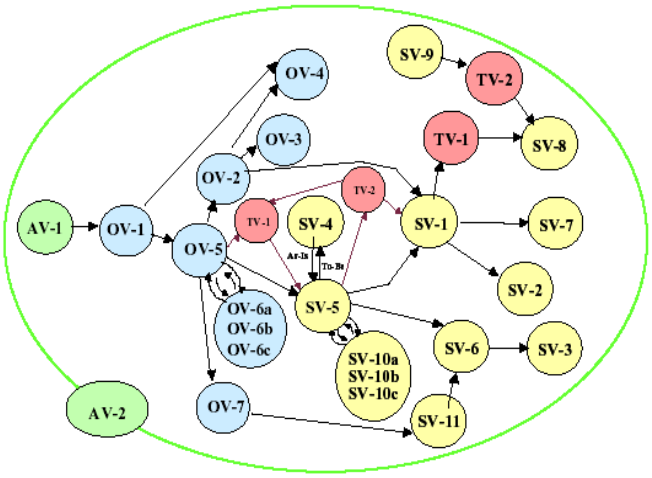


Figure 9. Relationships Among the Data Elements of DODAF [DODAF Version 1, Volume II February 2004.]

Applicable View	Framework Product	Framework Product Name	Net-Centric Extension	General Description
All View	AV-1	Overview and Summary Information	✓	Scope, purpose, intended users, environment depicted, analytical findings
All View	AV-2	Integrated Dictionary	✓	Architecture data repository with definitions of all terms used in all products
Operational	OV-1	High-Level Operational Concept Graphic	✓	High-level graphical/textual description of operational concept
Operational	OV-2	Operational Node Connectivity Description	✓	Operational nodes, connectivity, and information exchange need lines between nodes
Operational	OV-3	Operational Information Exchange Matrix	✓	Information exchanged between nodes and the relevant attributes of that exchange
Operational	OV-4	Organizational Relationships Chart	✓	Organizational, role, or other relationships among organizations
Operational	OV-5	Operational Activity Model	✓	Capabilities, operational activities, relationships among activities, inputs, and outputs; overlays can show cost, performing nodes, or other pertinent information
Operational	OV-6a	Operational Rules Model	✓	One of three products used to describe operational activity—identifies business rules that constrain operation
Operational	OV-6b	Operational State Transition Description	✓	One of three products used to describe operational activity—identifies business process responses to events
Operational	OV-6c	Operational Event-Trace Description	✓	One of three products used to describe operational activity—traces actions in a scenario or sequence of events
Operational	OV-7	Logical Data Model	✓	Documentation of the system data requirements and structural business process rules of the Operational View
Systems and Services	SV-1	Systems Interface Description Services Interface Description	✓	Identification of systems nodes, systems, system items, services, and service items and their interconnections, within and between nodes
Systems and Services	SV-2	Systems Communications Description Services Communications Description	✓	Systems nodes, systems, system items, services, and service items and their related communications lay-downs
Systems and Services	SV-3	Systems-Systems Matrix Services-Systems Matrix Services-Services Matrix	✓	Relationships among systems and services in a given architecture; can be designed to show relationships of interest, e.g., system-type interfaces, planned vs. existing interfaces, etc.
Systems and Services	SV-4a	Systems Functionality Description		Functions performed by systems and the system data flows among system functions
Systems and Services	SV-4b	Services Functionality Description	✓	Functions performed by services and the service data flow among service functions
Systems and Services	SV-5a	Operational Activity to Systems Function Traceability Matrix		Mapping of system functions back to operational activities
Systems and Services	SV-5b	Operational Activity to Systems Traceability Matrix		Mapping of systems back to capabilities or operational activities
Systems and Services	SV-5c	Operational Activity to Services Traceability Matrix	✓	Mapping of services back to operational activities
Systems and Services	SV-6	Systems Data Exchange Matrix Services Data Exchange Matrix	✓	Provides details of system or service data elements being exchanged between systems or services and the attributes of that exchange

Figure 10. The 26 Products of (SOA)-Based DODAF [DODAF Version 1.5, Volume II April 2007.]

Applicable View	Framework Product	Framework Product Name	Net-Centric Extension	General Description
Systems and Services	SV-7	Systems Performance Parameters Matrix Services Performance Parameters Matrix	✓	Performance characteristics of Systems and Services View elements for the appropriate time frame(s)
Systems and Services	SV-8	Systems Evolution Description Services Evolution Description	✓	Planned incremental steps toward migrating a suite of systems or services to a more efficient suite, or toward evolving a current system to a future implementation
Systems and Services	SV-9	Systems Technology Forecast Services Technology Forecast	✓	Emerging technologies and software/hardware products that are expected to be available in a given set of time frames and that will affect future development of the architecture
Systems and Services	SV-10a	Systems Rules Model Services Rules Model	✓	One of three products used to describe system and service functionality—identifies constraints that are imposed on systems/services functionality due to some aspect of systems design or implementation
Systems and Services	SV-10b	Systems State Transition Description Services State Transition Description	✓	One of three products used to describe system and service functionality—identifies responses of a system/service to events
Systems and Services	SV-10c	Systems Event-Trace Description Services Event-Trace Description	✓	One of three products used to describe system or service functionality—identifies system/service-specific refinements of critical sequences of events described in the Operational View
Systems and Services	SV-11	Physical Schema	✓	Physical implementation of the Logical Data Model entities, e.g., message formats, file structures, physical schema
Technical Standards	TV-1	Technical Standards Profile	✓	Listing of standards that apply to Systems and Services View elements in a given architecture
Technical Standards	TV-2	Technical Standards Forecast		Description of emerging standards and potential impact on current Systems and Services View elements, within a set of time frames

Figure 10. The 26 Products of (SOA)-Based DODAF [DODAF Version 1.5, Volume II April 2007 (Continued).]

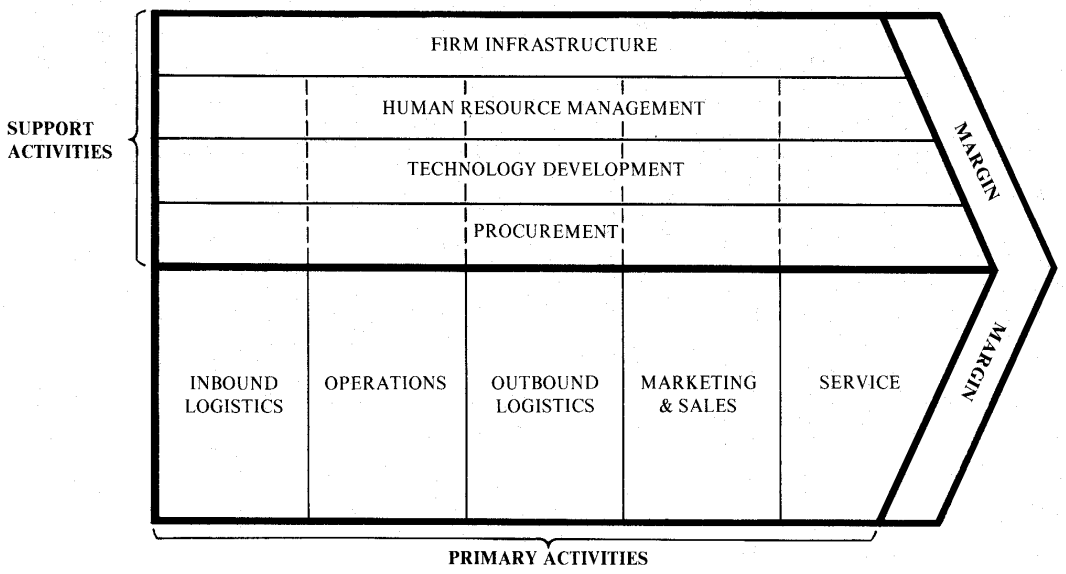


Figure 11. Value Chain [Porter 1985.]

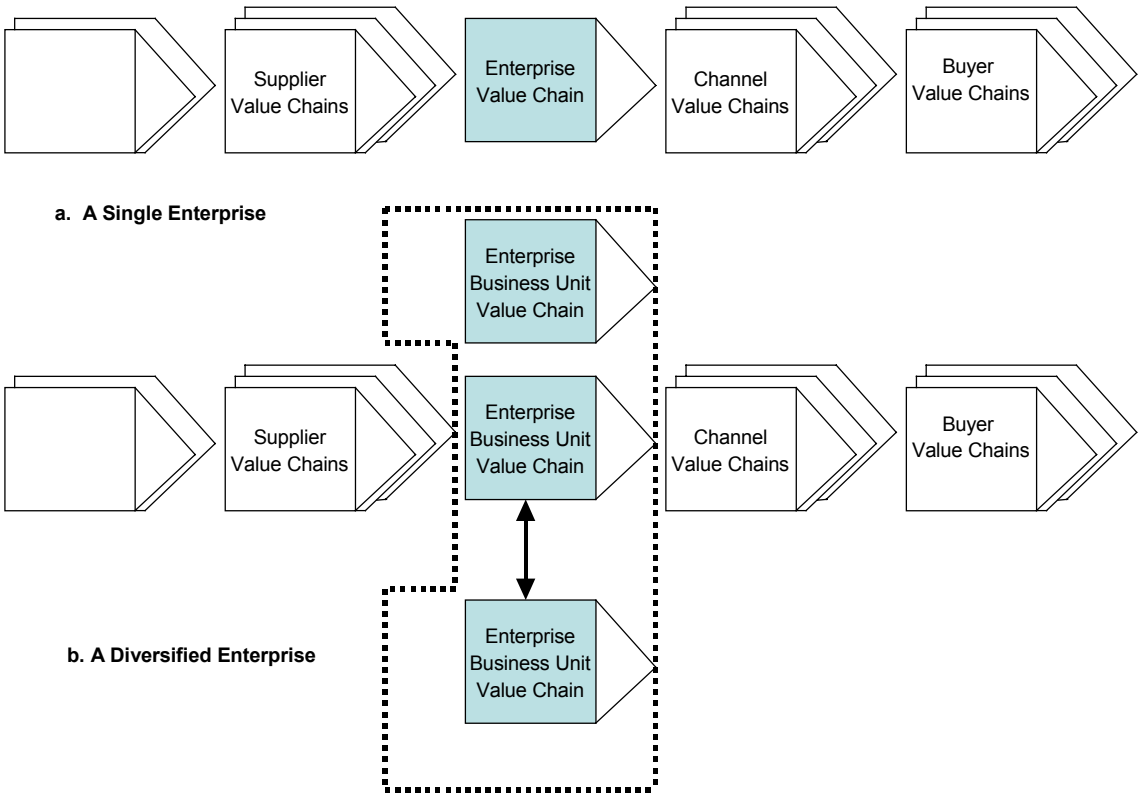


Figure 12. The Value System [Porter 1985.]; a. For a Single Enterprise; b. For a Diversified Enterprise.

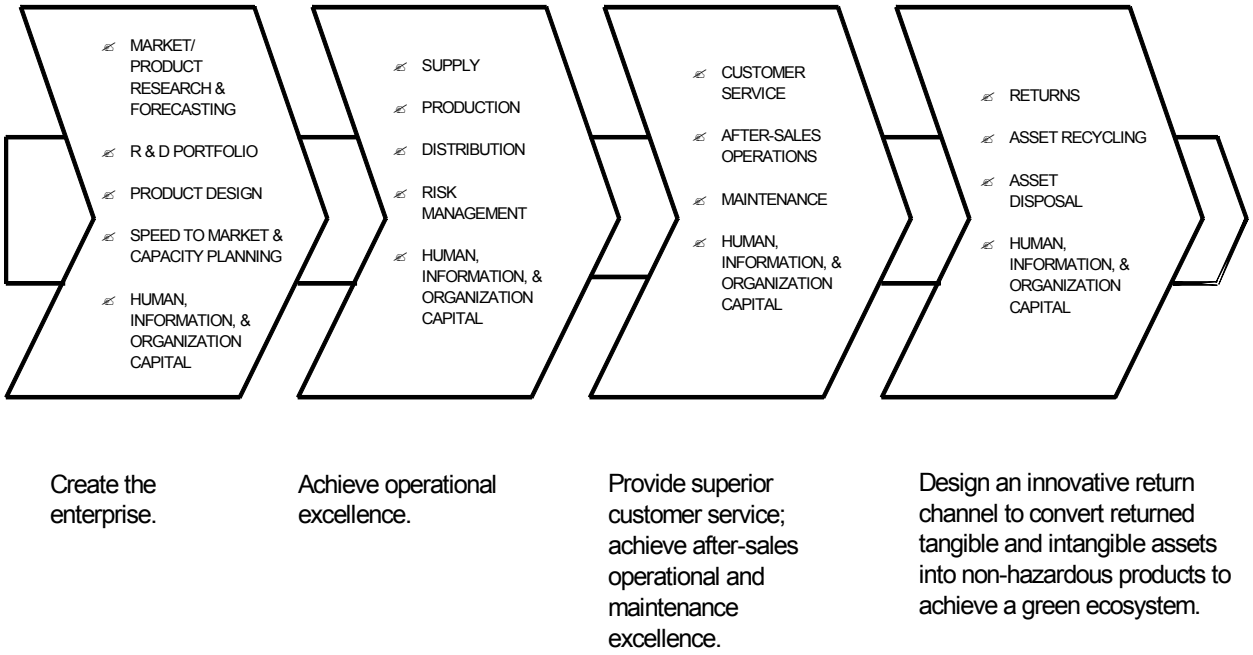


Figure 13. Proposed Value Chain Model, Based On The Four-Stage Lifecycle of a Product, Service or Systems-Of-Systems [Nyamekye April 2006.]

© Copyright Integrated Activity-Based Simulation Research, Inc. 2008

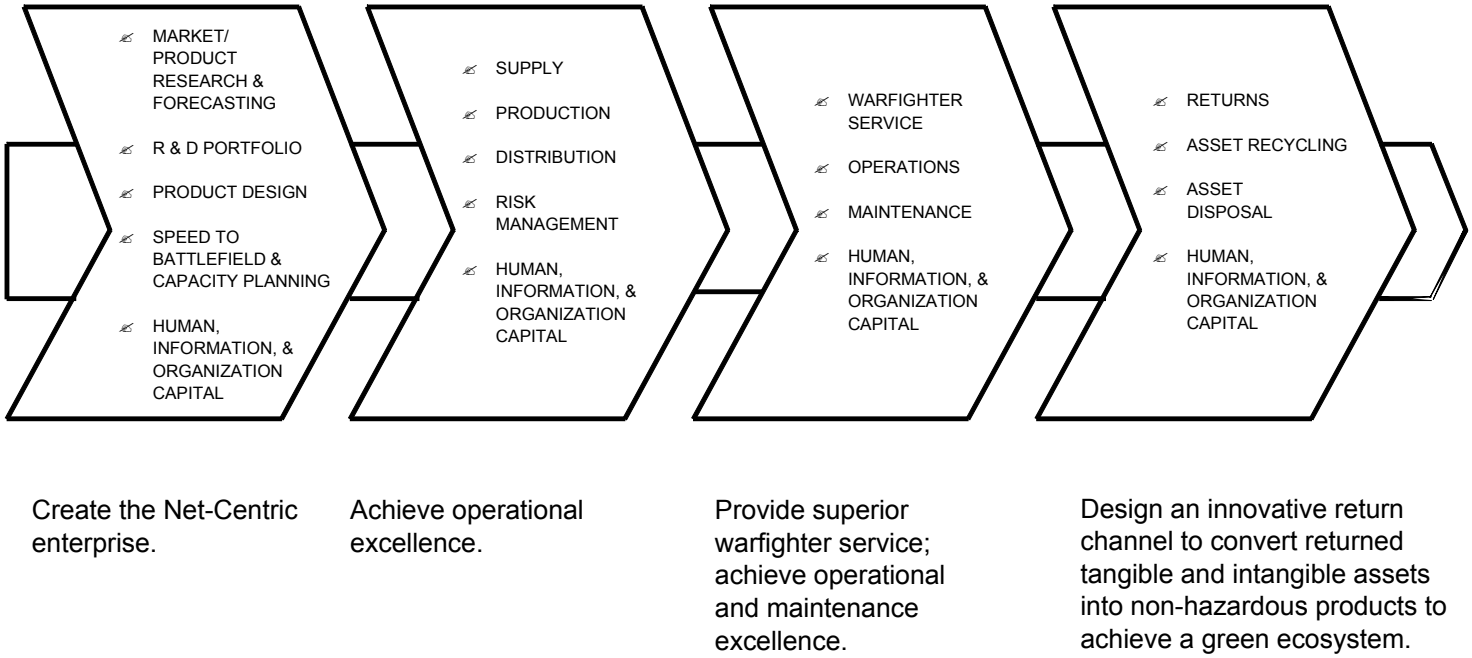


Figure 13a. Proposed DOD Generic Net-Centric Enterprise Value Chain Model, A Modified Version of Nyamekye's Model, Figure 13.

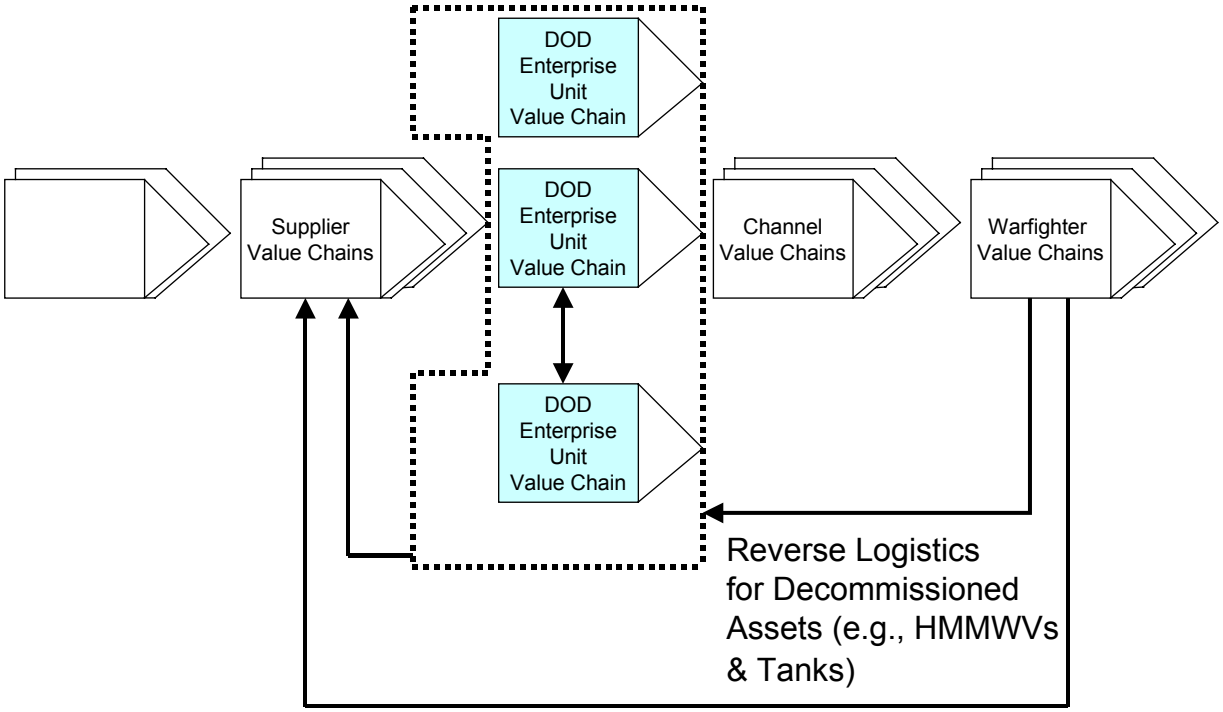


Figure 13b. Proposed DOD Generic Net-Centric Enterprise Value System Model, A Modified Version of Porter's Model, Figure 12.

© Copyright Integrated Activity-Based Simulation Research, Inc. 2008

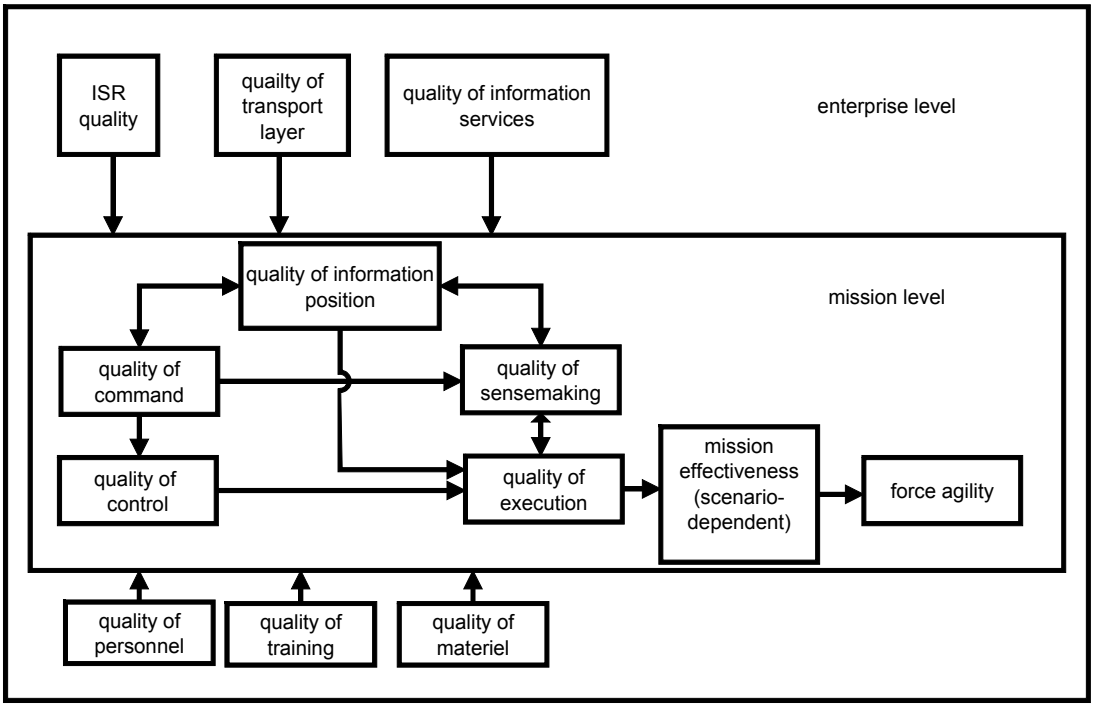


Figure 14. The MCP Value View Model for C2 Showing the C4ISR Systems [Alberts et al. 2006.]

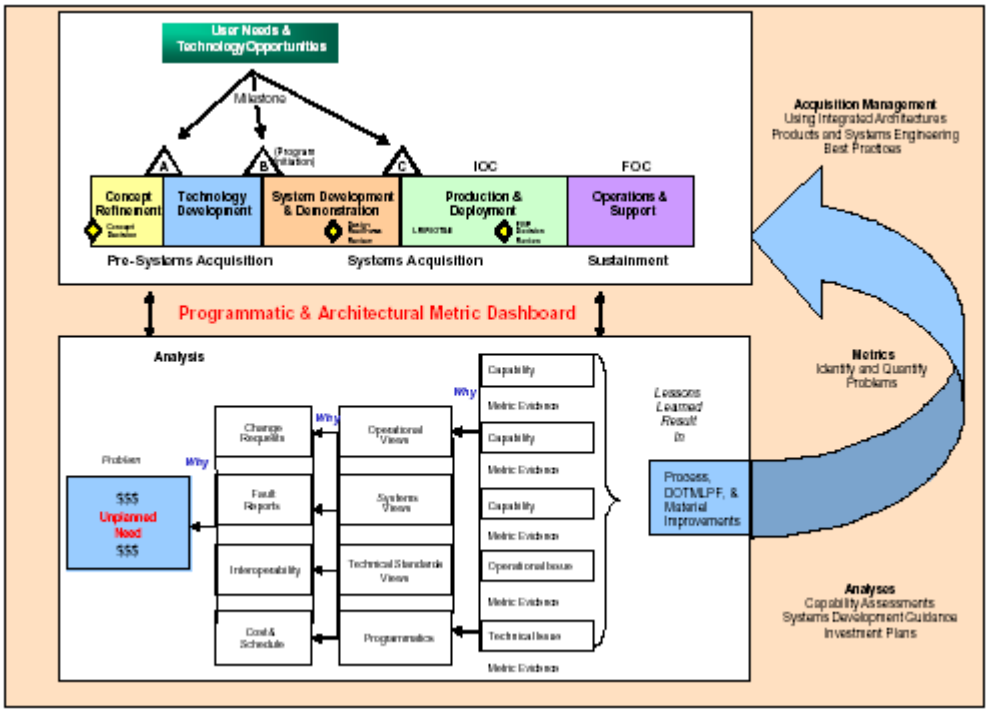


Figure 15. Acquisition Process and Architecture-Based Analysis [DODAF Version 1, Volume II February 2004.]

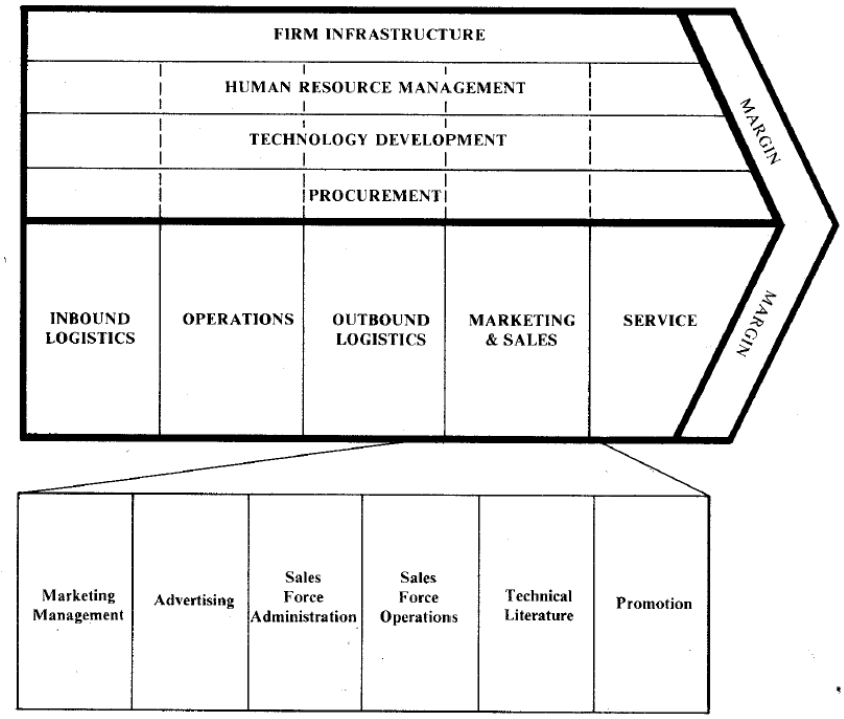


Figure 16. The Generic Value Chain Showing a Sub-Layer (Equivalent to OV-1) with Details of the Business Operations In The Sub-Layer [Porter 1985.]

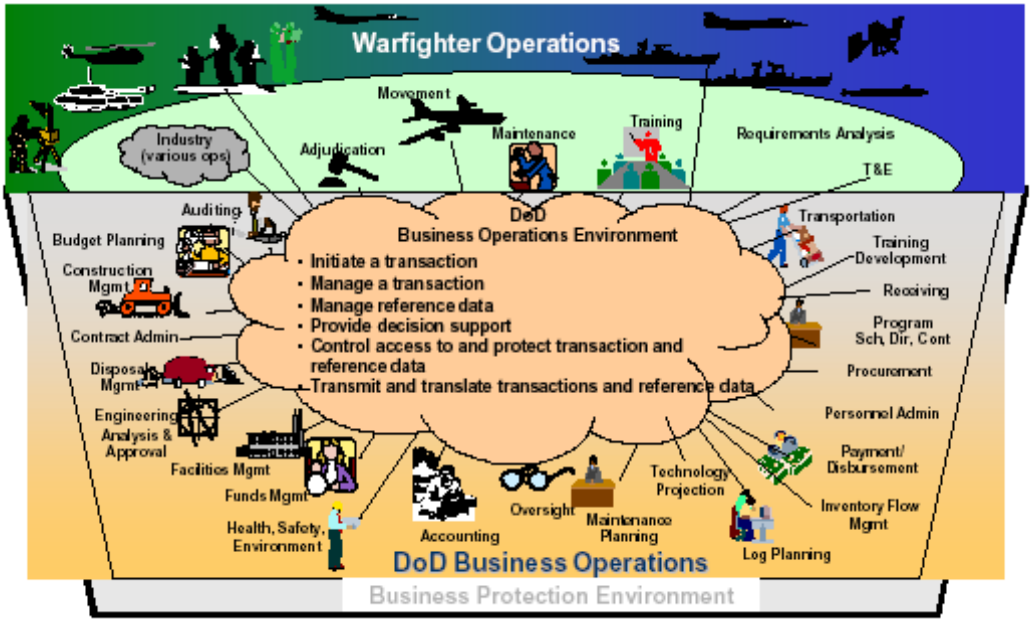


Figure 17a. The Concept Of Electronic Commerce In The DOD, Including The Relevant Business Areas And Support To The Warfighter, as an Example of OV-1 [Defense Electronic Business 2000.]

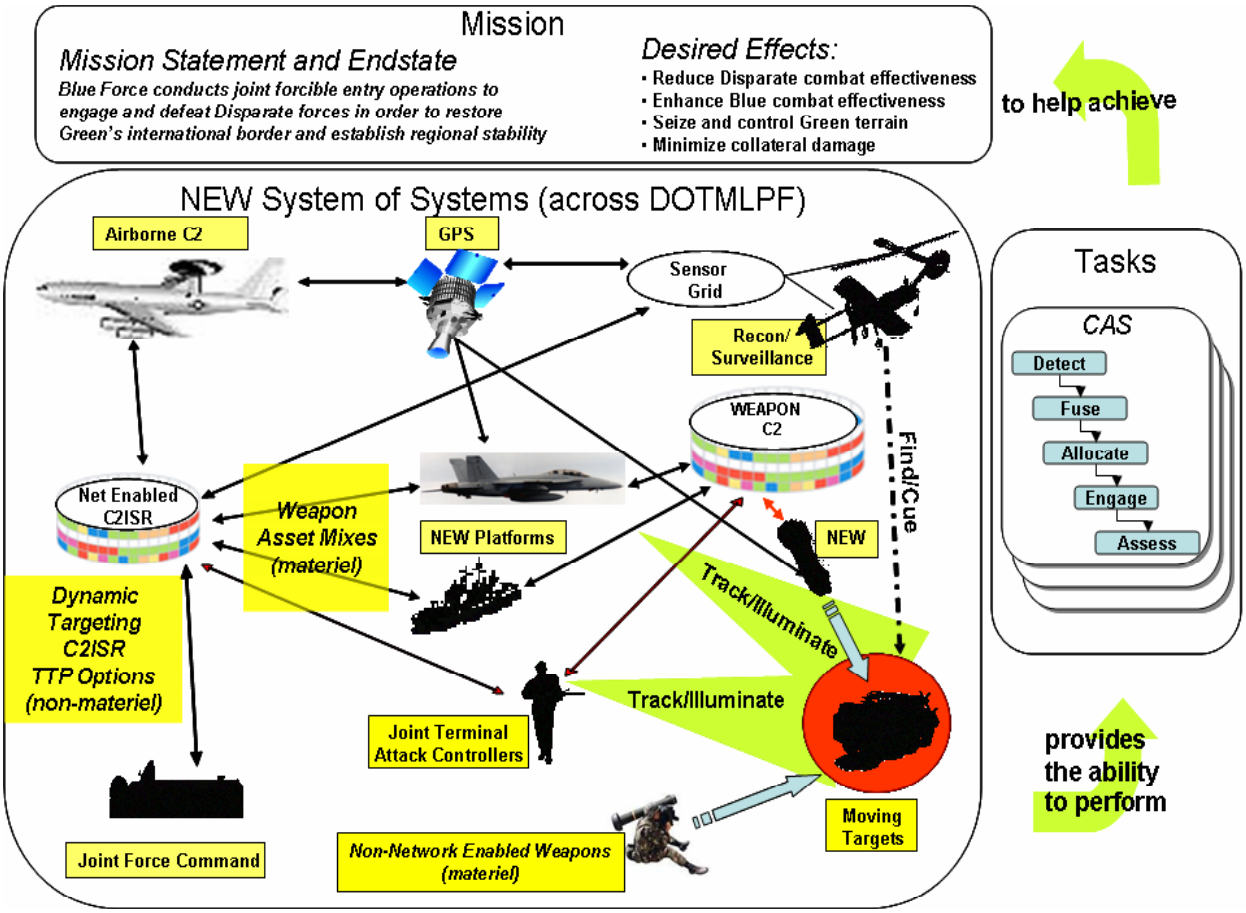


Figure 17b. Joint Network Enabled Weapon (NEW) Capability Operational Concept Graphic (OV-1), Depicting the ISR "Fuse" (Composite Task) [DODAF Version 1.5, Volume II April 2007.]

Figure 18. SOA Services As Application Silos (Departmentalized Services) [Dejong April 15 2007: "Used by permission from SD Times, BZ Media LLC. Copyright. All rights reserved."

PROCESSES	SUBJECT DATABASES																							
	Customer	Budget	Financial	Vendor	Procurements	Materials inventory	Fin. goods inventory	Orders	Cost	Sales	Sales territory	Payments	Planning	Employee	Salaries	Facilities	Work in progress	Machine load	Open requirement	Shop floor routings	Product	Product design	Parts master	Bill of materials
Market analysis	R									R	R		R								R			
Product range review									R				R											
Sales forecasting	R	C								R	R		C								R			
Financial planning		R							R				C											
Capital acquisition		R	C										R											
Funds management		R	R																					
Product design													R								C	C	C	
Product pricing		R							R												C	R		
Product spec. maint.																					R		C	C
Materials requirements				R															C		R		R	R
Purchasing				C	C																R		R	
Receiving				R	R	R															R		R	
Inventory control						C											R							
Quality control					C																			
Capacity planning				R												R		C	R	R				
Plant scheduling																R	C	R		R	R			
Workflow layout																C				C	R			
Materials control				R													R				R			R
Sizing and cutting																		R		C	R			R
Machine operations																		R		C				
Territory management	C							R			R													
Selling										C	C													
Sales administration								R			R													
Customer relations	R							R		R														
Finished stock control							C										R				R			
Order servicing	R							C													R			
Packing								R													R			
Shipping																					R			
Creditors and debtors	R			R								R												
Cash flow	R			R	R			R	R			R			R		R							
Payroll												C		R	R									
Cost accounting					R				C			C												R
Budget planning		C	R						R	R			R				R							
Profitability analysis									R	R														
Personnel planning			R											C	C									
Recruiting														R	R									
Compensation policy			R											R	R									

Figure 19. Cartesian Product (Cross Product) of Databases And Processes [Martin Book II 1990.]; C= Create, R=Read, U= Update, D = Delete

© Copyright Integrated Activity-Based Simulation Research, Inc. 2008

PROCESSES	SUBJECT DATABASES																							
	Planning	Budget	Financial	Product	Product design	Parts master	Bill of materials	Open requirements	Vendor	Procurements	Materials inventory	Machine load	Work in progress	Facilities	Shop floor routings	Customer	Sales	Sales territory	Fin. goods inventory	Orders	Payments	Cost	Employee	Salaries
Market analysis	R			R												R	R	R						
Product range review	R																					R		
Sales forecasting	C	C		R												R	R	R						
Financial planning	C	R																				R		
Capital acquisition	R	R	C																					
Funds management		R	R																					
Product design	R			C	C	C																		
Product pricing		R		C	R																	R		
Product spec. maint.				R		C	C																	
Materials requirements				R		R	R	C	R															
Purchasing				R		R			C	C														
Receiving				R		R			R	R	R													
Inventory control											C		R											
Quality control										C														
Capacity planning								R	R			C		R	R									
Plant scheduling				R								R	C	R	R									
Workflow layout				R										C	C									
Materials control				R			R		R				R											
Sizing and cutting				R			R					R			C									
Machine operations												R			C									
Territory management																C		R		R				
Selling																	C	C						
Sales administration																		R		R				
Customer relations																R	R			R				
Finished stock control				R									R						C					
Order servicing				R												R				C				
Packing				R																R				
Shipping				R																				
Creditors and debtors									R							R					R			
Cash flow									R	R			R			R				R	R	R		R
Payroll																					C		R	R
Cost accounting							R			R											C	C		
Budget planning	R	C	R										R				R					R		
Profitability analysis																	R					R		
Personnel planning			R																				C	C
Recruiting																							R	R
Compensation policy			R																				R	R

Figure 20. Partition of Databases and Processes Set Into Logical Functional Groupings Or Natural Business Areas, from Figure 15 [Martin Book II 1990; Gersting 1998.]; C= Create, R=Read, U= Update, D = Delete

© Copyright Integrated Activity-Based Simulation Research, Inc. 2008

LEAF ACTIVITIES	ENTITY TYPES															
	Employee	Contact Employee	Applicant	HR Compensation Regs, Plans, etc.	HR Benefits Regs & Plans	HR Staffing Requirements & Plans	Job Requisition	Stockholder	Boardmember	Misc. Contacts/VIPs	Financial Plans	Accounting Regs, Practices	Ledger Accounts	Customer Purchase Order/Invoice	Customer Payments	Other Invoice
Evaluate Financial Proposals																
Estimate Near - Term Earnings														R		
Prepare Budget	R	R		R	R						C	R	U			
Receive Funds												R		R	C	U
Pay Funds	R											R				
Report Finances	R											R	U	R	R	R
Administer Taxes												R	R		R	R
Maintain Financial Reg, Policies											R	U				
Audit Finances												R	R		R	R
Manage Financial Investments								C				R				
Plan Human Resources	R	R				U	U		R		R					
Acquire Personnel	C	C	C			R	R		U							
Position People in Jobs			R			R	U		R							
Terminate/Retire People	U	U							U							
Plan Career Paths	U			R	R	R										
Develop Skills/Motivation	U	U			R	R										
Manage Individual Emp Relations	U	U			R											
Manage Benefits Programs					C											
Comply with Govt HR Regulations	R			R												
Maintain HR Regs, Policies				C		C										

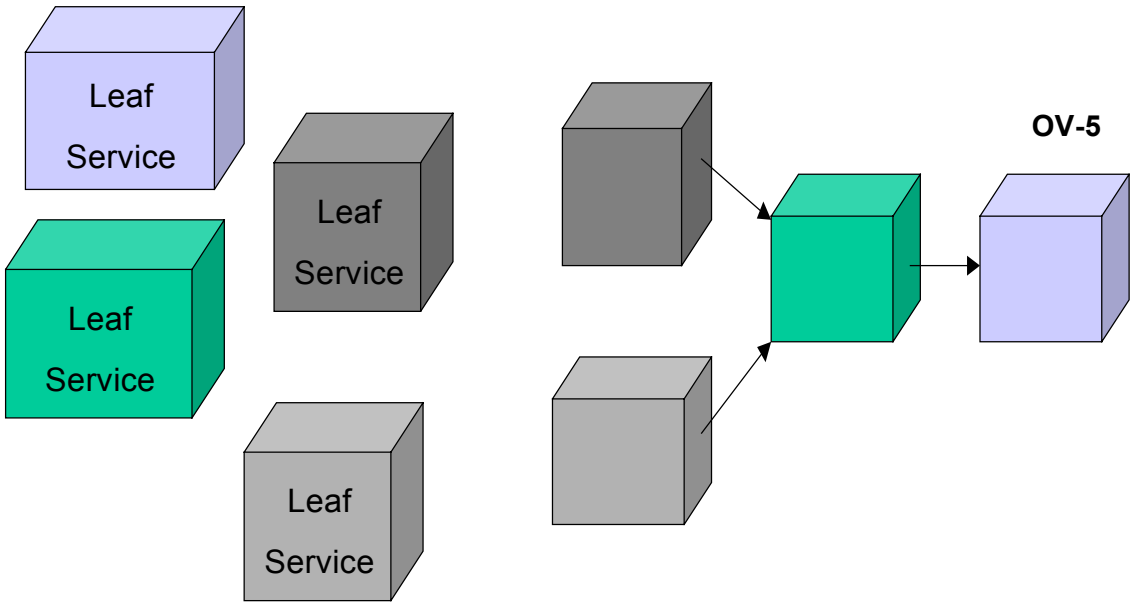
Figure 21. Cartesian Product (Cross Product) of Entity Types And Leaf Activities [Martin Book II 1990.] Note: The Last Two Natural Business Areas, Subsets 7 & 8 (From Figure 18) Are Used For Creating Figure 19. C= Create, R=Read, U= Update, D = Delete

© Copyright Integrated Activity-Based Simulation Research, Inc. 2008

LEAF ACTIVITIES	ENTITY TYPES															
	Financial Plans	Ledger Accounts	Customer Payments	Other Invoice	Accounting Regs, Practices	Stockholder	HR Staffing Requirements & Plans	Job Requisition	Contact Employee	Employee	Boardmember	Applicant	HR Benefits Regs & Plans	Misc. Contacts/VIPs	Customer Purchase Order/Invoice	HR Compensation Regs, Plans, etc.
Evaluate Financial Proposals																
Estimate Near - Term Earnings															R	
Prepare Budget	C	U			R				R	R			R			R
Receive Funds			C	U	R										R	
Pay Funds					R					R						
Report Finances		U	R	R	R					R					R	
Administer Taxes		R	R	R	R											
Maintain Financial Reg, Policies	R				U											
Audit Finances		R	R	R	R											
Manage Financial Investments					R	C										
Plan Human Resources	R						U	U	R	R	R					
Acquire Personnel							R	R	C	C	U	C				
Position People in Jobs							R	U			R	R				
Terminate/Retire People									U	U	U					
Plan Career Paths							R			U			R			R
Develop Skills/Motivation							R		U	U			R			
Manage Individual Emp Relations									U	U			R			
Manage Benefits Programs													C			
Comply with Govt HR Regulations										R						R
Maintain HR Regs, Policies							C									C

Figure 22. Partition Of Subsets, In Figure 19, Into Mutually Exclusive Subsets Of Leaf Activity-Entity Types Using The Cartesian Cross Product of Row And Column [Martin Book II 1990; Gersting 1998.]; C= Create, R=Read, U= Update, D = Delete

© Copyright Integrated Activity-Based Simulation Research, Inc. 2008



a. Leaf Services b. Composition of Leaf Services

Fig 23. a). Creating Leaf Services, and b). Composition of Leaf Services to Create OV-5s.

© Copyright Integrated Activity-Based Simulation Research, Inc. 2008

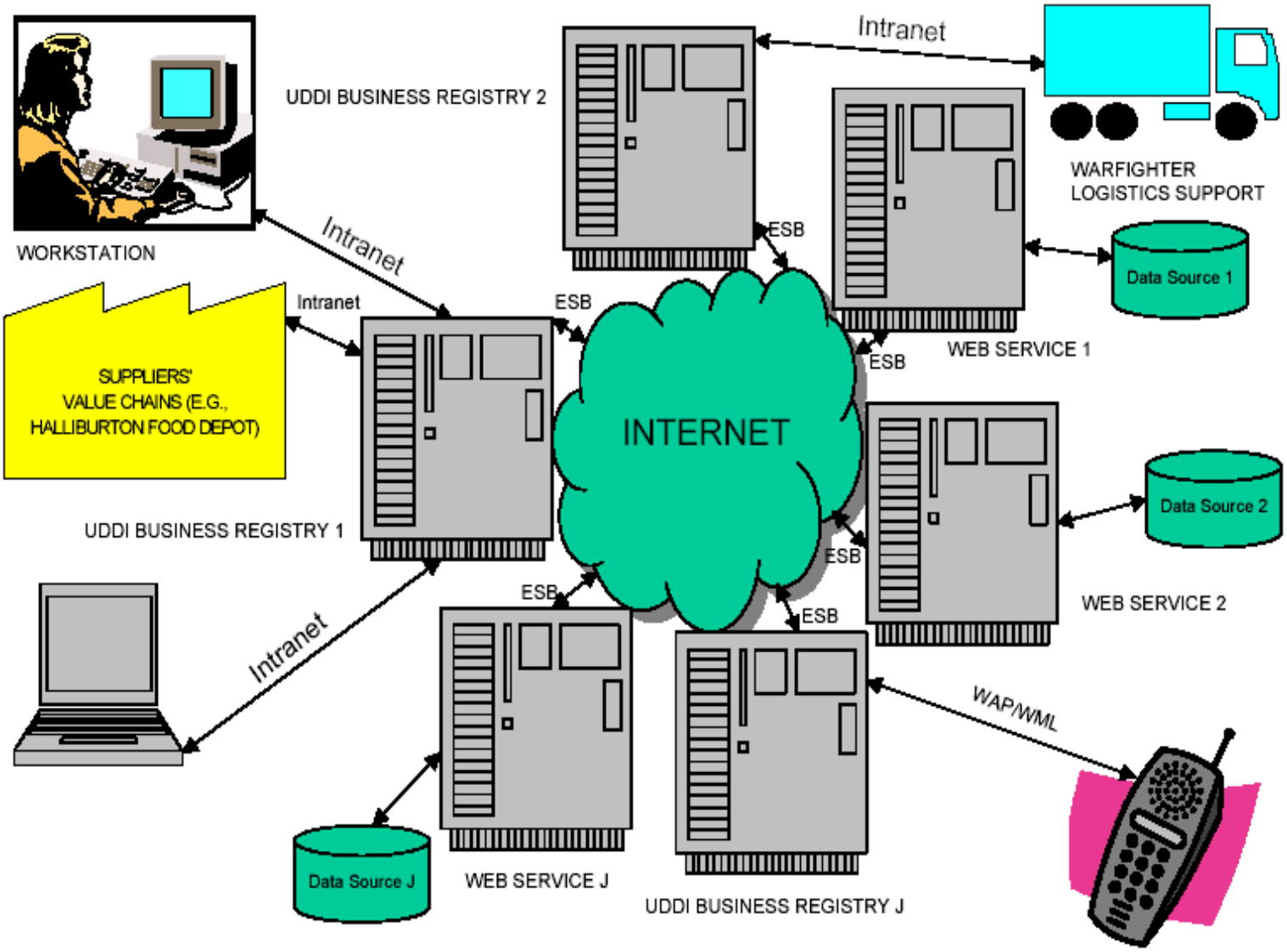


Figure 24. Service-Oriented Architecture (SOA) Model Of The Generic C4ISR, an updated version of Nyamekye's previous work [Nyamekye June 2007]: UDDI = Universal Description, Discovery and Integration The Universal Description, Discovery and Integration), UDDI provides a standard mechanism for registering and discovering Web services. According to Bloomberg et al. [Bloomberg et al. 2006], a Web service is *a standard-based, contracted interface to software functionality*. The Web Services Description Language (WSDL) provides a standard mechanism for describing the programmatic interfaces of the Web services [Zimmermann et al. 2005].

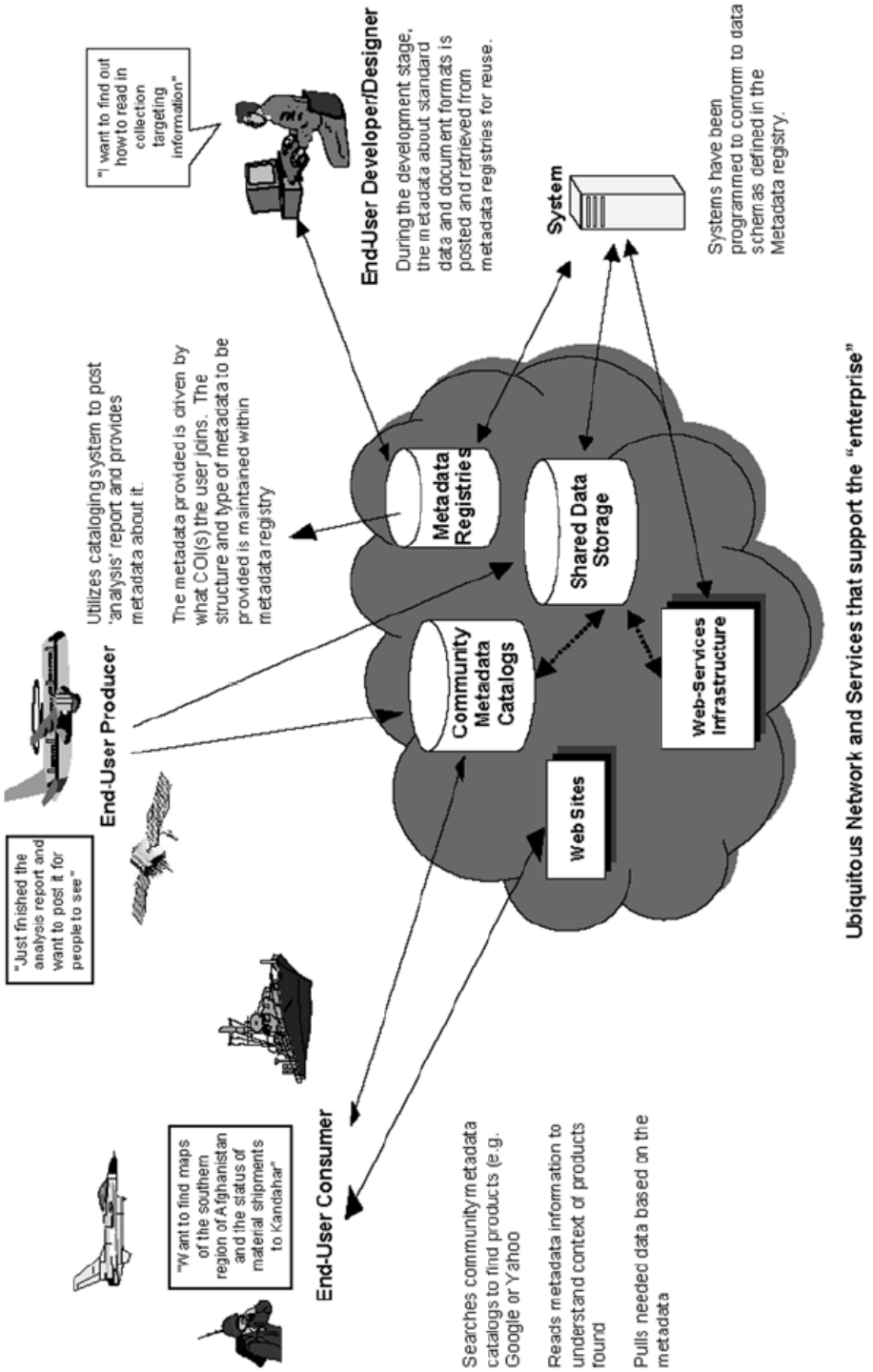


Figure 25. An SOA Blueprint for GIG User Services [Alberts et al. 2003.]

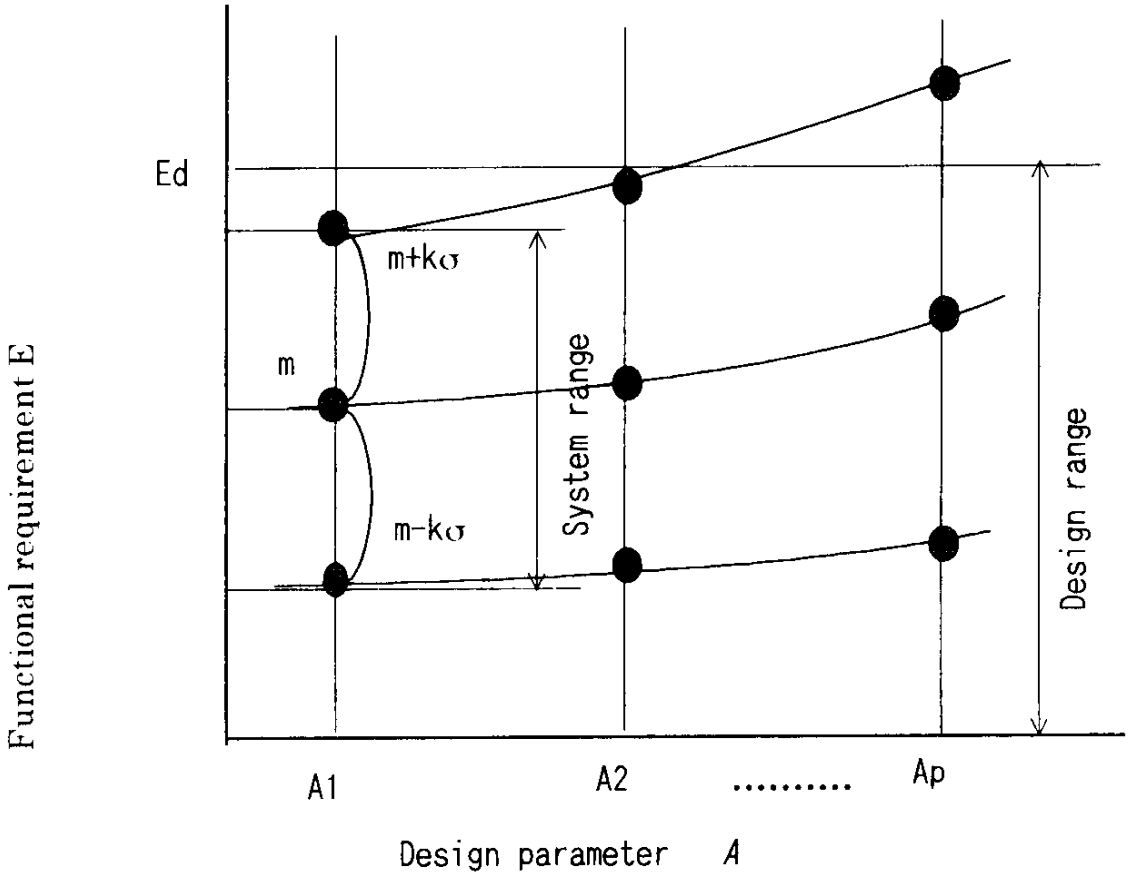


Figure 26. System Range of Design Parameter A for Functional Requirement [Nakazawa 2001.]

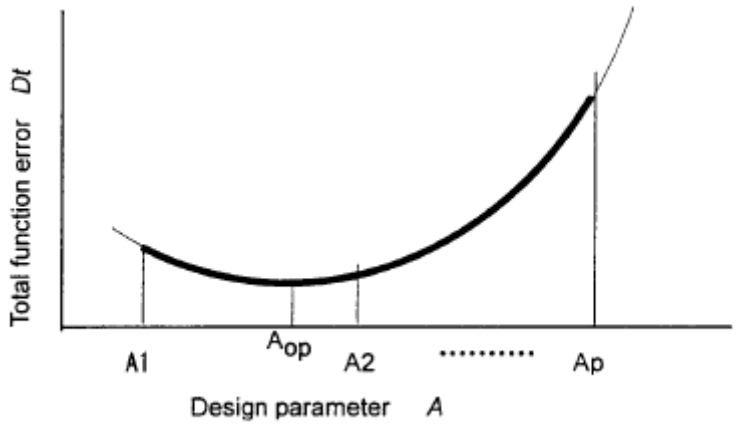


Figure 27. Total Information Content (Function Error Curve) [Nakazawa 2001.]

© Copyright Integrated Activity-Based Simulation Research, Inc. 2008

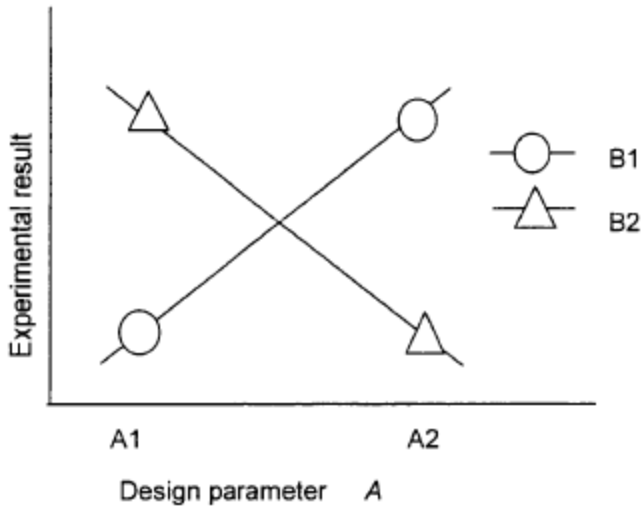


Figure 28. Experimental or Simulation Result For Functional Requirement, E, With Interaction Factors [Nakazawa 2001.]

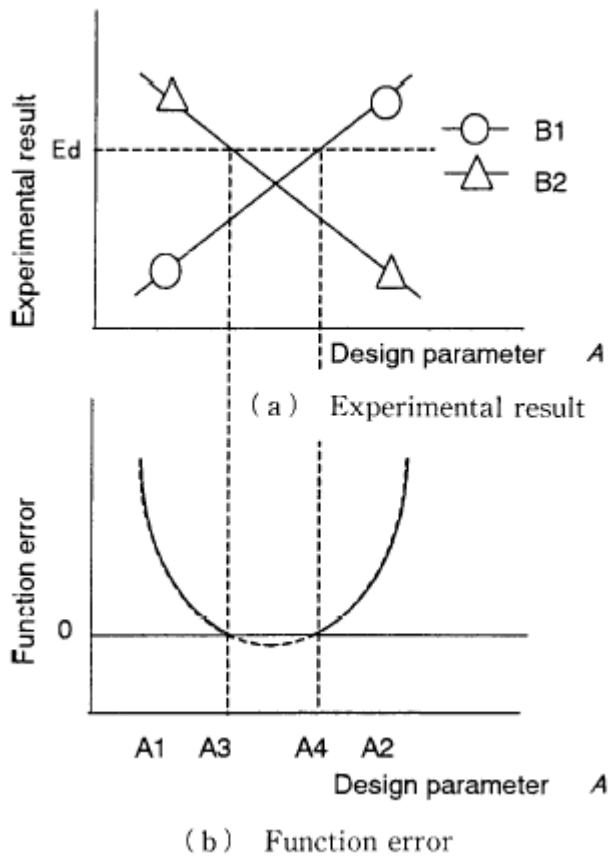


Figure 29. Information Content (Function Error Curve) for Functional Requirement, E, [Nakazawa 2001.]

© Copyright Integrated Activity-Based Simulation Research, Inc. 2008

NO	DESIGN PARAMETERS (DPs)				EXPERIMENTAL OR SIMULATION RESULTS FOR FUNCTIONAL REQUIREMENTS (FRs)		
	A	B	C	D	E	F	G
1	A1	B1	C1	D1	E1	F1	G1
2	A1	B2	C2	D2	E2	F2	G2
3	A1	B3	C3	D3	E3	F3	G3
4	A2	B1	C1	D1	E1	F1	G1
5	A2	B2	C2	D2	E2	F2	G2
6	A2	B3	C3	D3	E3	F3	G3
7	A3	B1	C1	D1	E1	F1	G1
8	A3	B2	C2	D2	E2	F2	G2
9	A3	B3	C3	D3	E3	F3	G3

Table 1. L_9 Orthogonal Table For Experimental or Simulation Design [Nakazawa 2001.]

DPs: $\deg_z, \lambda_i, \gamma$, μ', F_i, μ, L_i, SP, $\deg_z$, and network classification – Direct, Random, etc.
FRs: T_c (Equation 20)

© Copyright Integrated Activity-Based Simulation Research, Inc. 2008