Moving Integrated Product Development to Service Clouds in the Global Economy
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In a Network-centric World

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Abstract. Rapid advances in Information Technology have resulted in revolutionary changes in the way we run our businesses and live our daily lives. Network-Centric Operations (NCO) recognizes that interdependence (sharing information among many) is vital to an organization's future. Information must be quickly distributed, its value understood and the desired effect created. NCO occurs when systems are linked or networked by a common infrastructure, share information across geographic borders, and dynamically reallocate resources based on operational needs. NCO is an environment where seamless collaboration between networks, systems or elements within systems is possible. This network will provide decisions makers with information from thousands of cloud nodes to produce a complete picture of Cloud Manufacturing viewed as a three-dimensional chessboard. Enabling this seamless networking capability is an information and communication Strategic Architecture Reference Model (RFM). The RFM works with both legacy and future systems and platforms to ensure interoperability with nodes that follow the same set of standards. Understanding System-of-Systems Engineering (SOSE) is critical to a robust architecture development of NCO systems. There are five System-of-Systems (SoS) characteristics [1] but the dominating one is emergent behavior. This non-linear behavior will impact architecture development. We have little understanding of the principles of SOSE in which especially the dominating behavior of emergence. Proposed research subjects are Boltzmann distribution probability theory, and agent-based emergent behavior model, etc. Due to the immature development and diversified opinions, there does not exist a single unified consensus for processes involved in System-of-Systems Engineering.

Keywords. Network-Centric Operations, Cloud Manufacturing, Architecture Reference Model, Systems of Systems Engineering

Introduction

During the "Operational Desert Storm" war, also called the "Persian Gulf War" (August 2, 1990 – February 28, 1991), the concept of "Network Centric Operations (NCO)" was conceived. It was realized that the United States Department of Defense (DoD) acquired weapon systems in isolation. But it does not use weapon systems in isolation. All the systems are required to work together at the same time in the battle field to win a war. They have to be networked to exchange information for the right information in the right form to the right place at the right time for the right decision to enable their warfighting capabilities. The NCO applications are not restricted to military only. In fact, there are more commercial NCO applications than military, for example, Global Communications, Navigation, and Surveillance System (GCNSS) that can be used for Tsunami warning, weather forecasting for National Oceanic and

Atmospheric Administration (NOAA), e-Enabled Airline for the Integration of airplanes, people, and operations, and enhancing the global Next Generation (NextGen) Air Traffic Management (ATM), in a System-of-Systems (SoS) environment (everything and everyone connected).

We are now in the Information Age – the second industrial revolution, according to John Chambers, the CEO of Cisco Systems, Inc. We are drowning in information [2]; immersed in data surrounded by standalone information systems and starving for knowledge. NCO is the solution and is an environment where collaboration between platforms, systems, and devices, such as satellites, aircraft, or PDAs, is possible. For an element to become a network-centric node on a network, it needs to use a common information and communication architecture. It is illustrated in Figure 1. Once an element becomes a node, it has the ability to function and collaborate with other nodes both inside and outside its resident domain. As more nodes are introduced into the environment, the network becomes more robust, much like the growth and expansion of the Internet. And like the Internet, network centric nodes depend on each other to provide multiple streams of connectivity for the movement of information from point to point.

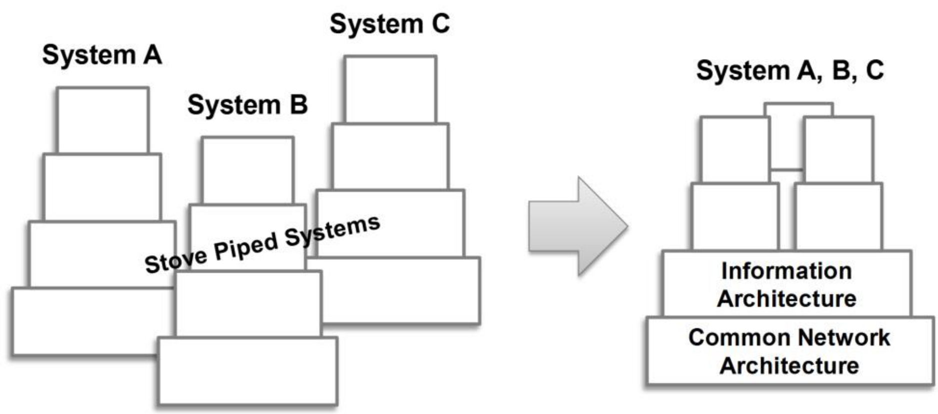

Figure 1. Common Architecture.

One of the several benefits to a network-centric environment is the increase in situational awareness whether we are operating under battle conditions, protecting our homeland, or managing an enterprise. The interoperability between networks and nodes allows decision makers to make better, more informed decisions quicker and more accurately.

1. The Commercial Applications

The non-military organizations using network centric architectures are themselves very diverse, ranging from retailing and search to manufacturing and developmental. The following provides an overview on how network centric approaches and architectures are used in several different non-military organizations:

'Bricks and Mortar' Retailer – The best example is Wal-Mart. Wal-Mart's architecture is described as a sensor grid (the point of sale devices) coupled to a transaction grid that allows the entire supply train to anticipate and respond to evolving marketplace needs and trends [3]. Wal-Mart's assent to the top of the retail domain began in the 1960's and 70's with the building of its own distribution infrastructure. In the 1980's, Wal-Mart took a significant step as an early adapter of bar code technology which gave it the information to implement consumer trend forecasting software. In 1985 the company began development of another critical piece of technology – the "Retail Link" system that provided detailed consumer data and linked suppliers into the system. This system which became one of the centerpieces of Wal-Mart's network centric system took years to develop and cost over 4 Billion dollars to develop [4]. It has been estimated that this $4 Billion investment by Wal-Mart resulted in a 10 fold investment, i.e. $40 Billion, in information technology by its suppliers and was a major productivity driver for the economy in the late 90's [5].

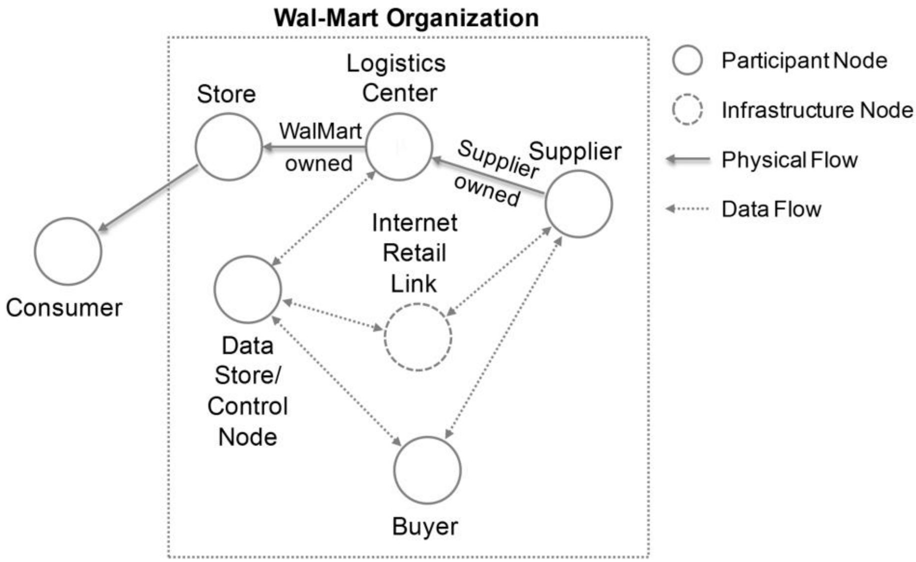

Figure 2. Operational Node Connectivity Diagram for Wal-Mart's Retail to Supplier Flows.

As Wal-Mart grew, its traditional top-down supply and demand control methods grew less effective. In response the company developed a sensory capability, primarily its point of sale, bar code reading registers and a pervasive transaction grid – feeding the sensory network inputs in near real time to the company's decision makers and its large web of suppliers. The result as explained by General Electric's Jack Welch was that "When Wal-Mart sells a (light) bulb on the register, it goes to my factory instantly- I (General Electric) make the bulb for the one they just sold. The enterprise system is now totally compressed with information." [3]. This is the Wal-Mart Network Centric System. A greatly streamlined supply chain with supplier relationships that have been largely automated. The operational node connectivity for the resulting system is illustrated in Figure 2. The physical flow shown in the figure starts when a supplier ships stock to a Wal-Mart distribution center. At this point Wal-Mart takes ownership of the stock and usually cross-decks (puts the goods on an outbound shipment without warehousing) the shipment and send to the end user stores where it is sold to a consumer [6]. On 12 July 2014, Wal-Mart was dealing with 100 million consumers weekly and over 36 million customer transactions daily [7].

The Wal-Mart infrastructure includes over 4,253 stores, 158 distribution centers and over 2 million employees [8]. Every distribution center supports 90 to 100 stores in a 200-mile radius. On the supplier side of the system, there were over 60,000 suppliers in 2014. Wal-Mart has 2 million employees. Total amount of money spent at Wal-Mart every hour of every day is $36 Million. Wal-Mart's revenues was $421.89 Billion, on par with the GDP, ranked the world's 25th as a country [9].

'eCommerce' Business – The best examples are two commercial NCO architectures where the consumer/user interactions are also networked - Amazon and eBay. These businesses typically are able to use the web to do away with the physical store infrastructure and centralize their operations which exhibits a one-to-many pattern. The supply chain relationships with vendors may be very similar to that discussed to the Wal-Mart example. Basic enablers for this aspect of the business are again sensors (barcodes, sales info), a networked supply chain, a large information store with rapid processing functionality and responsive technology development ability. For the online businesses, the technology development approach is typically extended to allow significant participation by developers or organizations outside of the core organization. For example Amazon has an 'Amazon Web Services Program' that involves on the order of 30,000 to 50,000 outside developers [10] [11].

The relationship between the system and the consumers can be potentially more complex. There is no longer a store site where the consumer can physically inspect the goods. On the system's side, credit card and internet payment mechanism such as the PayPoint system allow for relatively trustworthy payments. On the consumer's side there is the retailer's reputation and the reputation of well-known or defined brands or makes of products. The lack of the ability to physically examine and compare goods and interact with live salespeople can still be a barrier to these systems.

2. Architecture Reference Model

Network communications is the foundation to make systems linked or networked to share information across geographic borders and dynamically reallocate resources based on operational needs. The basics of network communications are to transmit data throughout the network, between systems, devices or computers. The data are transferred through a series of layers. Each layer can be developed and designed separately as long as the interfaces between layers are established. These layers form the Architecture Reference Model (ARM). There are many ways to describe and design the network communication layers; therefore, there are many ARMs. Over the past decade new approaches to organization and enterprise challenges have emerged using the capabilities enabled by networked systems. These networked approaches have revolutionized the means of conducting business and operations in domains across a wide spectrum of activities. These network based approaches have been used by a variety of organizations to implement network centric operations in their central activities.

The purpose of a reference model is to provide a common conceptual framework that can be used consistently across and between different implementations and is of particular use in modeling specific solutions. A reference model is an abstract framework for understanding significant relationships among the entities of some environment. It consists of a minimal set of unifying concepts, axioms and relationships within a particular problem domain, and is independent of specific standards, technologies, implementations, or other concrete details. It is in an abstract format leading to reality for understanding relationships.

An ARM is intended to provide a high level of commonality, with definitions that should apply to all architecture models in that category or application. It is a description of all of the possible software/hardware components, component services (functions), and the relationships between them. It further describes how these components are put together and how they will interact. It enables the development of specific architectures using consistent standards or specifications supporting that environment.

In the network communications domain, an ARM basically consists of three layers as shown in Figure 3: They are the Top "Application" Layer comprising application and presentation aspects; the Middle "Internetwork" Layer comprising the transport and network aspects and the Lower "Hardware" Layer comprising the data link and physical connection aspects. Each layer can be decomposed to more layers. How many layers and types of layers depending on the specific applications or system requirements for each ARM. They are: Open Systems Interconnection Reference (OSI) Model, Global Information Grid (GIG) Reference Model, DoD Technical Reference Model, Strategic Architecture Reference Model, and Net-Centric Company Architecture Reference Model. There are more ARMs than mentioned here. They can be classified to four categories based on applications:

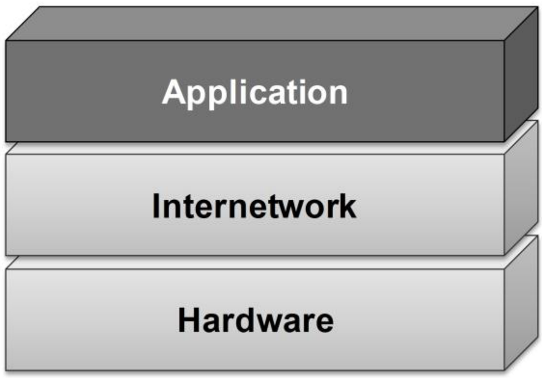

Figure 3. Basic Layers for Architecture Reference Model.

1. Internet Application includes OSI Model and Internet Model.
2. Military and Government Application includes Global Information Grid Model and DoD Technical Reference Model and Federal Enterprise Consolidated Reference.
3. General (Military and Commercial) Application includes Strategic Architecture Reference Model and The Open Group Architecture Framework (TOGAF) Technical Reference Model (TRM).
4. Company and Organizational Application include Net-Centric Company Model.

The ARMs proposed for different applications are basically consisting of three layers. They are Application Layer, Internetwork Layer and Hardware Layer. As shown in Figure 4, each layer will be expanded with increasing levels of detail and specificity at each successive level from an abstract decomposition of the functional units of a network node to specifications for the component pieces used to implement the functionality. The OASIS Service Oriented Architecture (SOA) Reference Model produced an IT industry standards body [12]. This Service Oriented Architecture (SOA) Reference Model is an abstract framework for understanding significant entities and relationships within a service-oriented environment, and for developing consistent standards/specifications supporting that environment. Because SOA makes use of the concept of web services, it is viewed as a key foundation to achieving the GIG. One of the greatest challenges to the GIG has to do with the acquisition planning, funding and scheduling of the associated business models for SOAs.

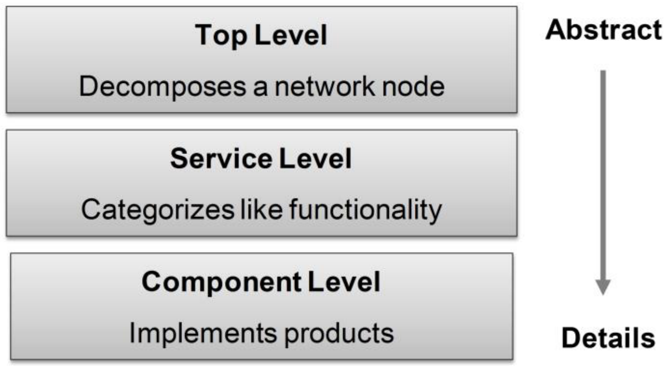

Figure 4. ARM Follows a Top-Down Design.

The second industrial revolution is the Net-Centric Operations (NCO). The deployment of NCO depends on network communications. The basics of network communications are to transmit data throughout the network. The data are transferred through a series of layers. ARM defines the arrangement and composition of layers. The details of this section can be referred to Hsu [13].

3. System-of-Systems Engineering

The network centric infrastructure consists of the network, networked sensors and networked information stores and analysis functions. Each node is an independent system. The participants, suppliers and consumers are all independent systems; therefore, by nature, NCO is a system-of-systems (SOS). To design and/or develop systems architecture for NCO needs to understand the principles of System-of-Systems Engineering (SOSE). Unfortunately, the development and understanding of SOSE fundamentals is at infant stage. SoS exhibits emergent behavior that adds more complexity to SOSE. This non-linear emergent behavior will impact architecture development, risk management, verification and validation strategy, reliability and maintainability assessments, and trade study methodology. Unplanned, unexpected behavior is expected to emerge between component systems. Emergent behaviors are characteristics that arise from the cumulative actions and interactions of the constituents of a SoS. It displays a global complexity that cannot be adequately managed by hierarchical structures and central control. The behavior and/or performance of the SoS cannot be represented in any form that is simpler than the SoS itself. There is no simple way (i.e. simpler than the SoS itself) to relate the functions of the parts to the functions of the whole. The traditional hierarchical functional decomposition is no longer valid due to the non-linear characteristics of emergent behavior; however, since the emergent behavior is non-existent in each component system, the hierarchical functional decomposition is still applicable to component system level.

The first challenge of architecting a SoS is at the top SoS level incorporating the emergent behavior. The next challenge is how to flow down the SoS level architecture to the component system level if they are hierarchical structures especially for the legacy systems. The model-based architecture-centric approach may be one of the answers. The customer requirements in the form of CONOPS (Concept of Operations) model(s) are captured in the SoS architecture model(s). The component system architecture models can continue to capture CONOPS of component system level and the data flow from the upper SoS-level architecture. The subsystem architecture models can continue to capture CONOPS of subsystem levels (if there are any) and the data flow from the component system-level architecture. In this architecture top down development sequence the layered architecture models are developed and shown in Figure 5. In a layered model, the overall SoS is broken down into different collections of services, with each collection expressing the services that are available to layers above it in the “protocol stack”. Layered architectures allow different developers to work in parallel and insure that changes in one layer of the protocol do not interfere with operations above and below that layer. Thus, layered architectures implement loose coupling between the services that makes up the overall SoS. System design including hardware and software will be based on architecture models in different levels. The details of this section can be referred to the course materials [14].

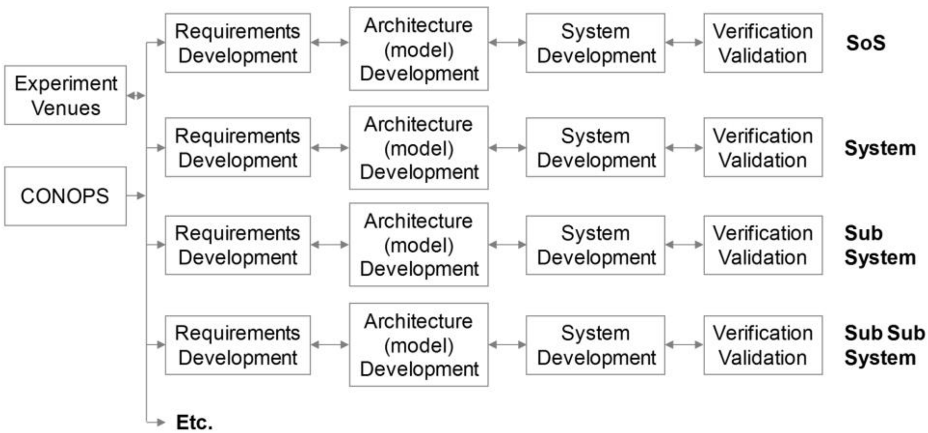

Figure 5. Layered Architectures of a System-of-Systems.

4. Conclusions

The applications of the network centric systems are unlimited for both military and non-military. There are more commercial applications, such as, Wal-Mart, Amazon and eBay as mentioned in the above, including applying to Cloud manufacturing, Service Clouds and e-Enabled airline operations, etc. The network centric systems in the commercial domain displayed a number of interesting capabilities. These included the means to integrate extremely large groups of users into effective systems-of-systems with time constants measured on the order of hours/days. The basic network centric enablers used in these systems fall into the following but not limited to these categories:

1. The inclusion of more and more participants into the system-of-systems, from suppliers to consumers to developers.
2. The means to address manipulation of the system by participants.
3. The incorporation of near real-time feedback and monitor mechanisms at the system-of-system level (eBay and Wal-Mart) for extremely large scale systems.
4. A shared situational awareness in most cases.

Specific Skills Required for NCO:

Systems Engineering - Focuses upon the design of a complex system that involves many individual systems. The skills that have to be developed:

1. System-of-Systems Engineering.
2. Architecture Framework.
3. Requirements and Functional Modeling.
4. Other pertinent systems engineering skills.

Large-scale Systems Integration:

1. Organizational competency beyond design-oriented aspects and includes production and supplier management, etc.
2. Ability to manage many tasks that are needed to produce a solution that meets customer's needs.

Networking Technologies:

1. Network theory.
2. Communication technology.
3. Hardware.

The understanding and research of SOSE is at the beginning phase. Proposed research subjects include Boltzmann distribution probability approach, agent-based emergent behavior model, statistical distributions, and optimizing interoperations of network systems, and other methods. Due to the immature development and diversified opinions, there does not exist a single unified consensus for processes involved in System-of-Systems Engineering.

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