Modular Open Systems Approach: An Effective Business Strategy for Building Affordable and Adaptable Architectures

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Abstract

A Modular Open Systems Approach (MOSA) is an integrated business and technical strategy for developing flexible and standards-based architectures to achieve affordable, interoperable, and sustainable systems. As a business strategy, it capitalizes on reducing the total system ownership costs via application of the latest products and state-of-the-art technologies from multiple sources. As a technical strategy, MOSA utilizes a modular design approach and widely supported industry standards for key system interfaces. The aim of this paper is to conduct an exploratory research to (1) to assess the degree of understanding of modular open systems approach in organizations; (2) identify the obstacles and barriers toward implementing MOSA as a business strategy; and (3) to identify the principle factors that determine the success or failure of MOSA. To this end, a survey of 170 organizations was conducted. The results indicate……

Introduction

Architecture means different things to different people. Some definitions are complex, confusing, and depicted in very long paragraphs. For example those in Software Architecture for Product Families: Principles and Practice [1], or the one proposed in the UML Modeling Language User Guide [2]. Other definitions are simpler and more concise (e.g., see [3] and [4]). The most widely-used definition is perhaps the one provided by the Institute of Electrical and Electronics Engineers (IEEE) that defines architecture as the structure of components, their relationships, and the principles and guidelines governing their design and evolution over time (IEEE Standard 610).

Generally speaking, there seems to be a consensus that the architecture is the structure not only of the system, but of its functions, the environment in which it will live, and the process by which it will be built and operated [4]. It is the highest-level conception of a system in its environment and includes the structure and behavior of the whole system in that environment, to show how the system will meet its requirements [5]. Additionally, an architecture is believed to be a base for reasoning about a system [6], emphasizing transformation rather than decomposition, applying series of representations that have different motivations, uses, views, and semantics, etc [3].

An open system design strategy depicts the structure of components, their interrelationships, and the principles governing their design and evolution through adherence to modular design tenets and widely-supported and consensus-based standards. Open architectures rely on physical modularity and functional partitioning of both hardware and software to create the flexibility needed for replacing specific subsystems and component without affecting others. By developing an open system architecture, the IT planners and system integrators/architects will build flexibility into systems to achieve enduring interoperability, integrability, affordability, adaptability, commonality, and supportability.

Open architecture complies with all the characteristics of a typical architecture. It delineates the structure of components, their relationships, and the principles and guidelines governing their design and evolution over time. It also depicts the functions and the environment of a system at a high conceptual level, and shows how by using open interfaces the system can meet its present and future requirements. What makes an open architecture unique is adherence to modular design principles, disciplined definition of interfaces, and application of widely supported and consensus-based interface standards [7]. The use of modular design tenets (e.g., maximal cohesiveness of the functions and minimal coupling among elements) make it easier to convert functional architectures to flexible and long lasting design architectures. The application of open standards will also result in capability to quickly leverage the investment and the know-how of industry leaders. These attributes of an open architecture will enable quick development and cost-effective change of the system as requirements evolve and new technologies become available. A. Open Architecture Principles:

As discussed later, adherence to 4 essential principles are needed to develop an open architecture. They are continuing market analysis; application of modular design principles; preference for use of open standards for selected interfaces within the system; and effective interface management. The following paragraphs provide further details on these principles as well as on the other conceptual foundation of the proposed open architecture development model.

1. **Continuing market analysis.** Development of a robust and long lasting open architecture is a function of depth and quality of the market analysis performed on a continuing basis. Such market analysis forms the foundation for assessing the organizational hygiene on a continuing basis, selecting appropriate standards and technologies for various systems comprising the organizational system, and making decisions to discard the obsolete and inefficient hardware and software products with more capable and technologically superior ones. The organization must gather market intelligence about emerging technologies, standards, and compliant products continually and effectively to determine the effectiveness and appropriateness of the open architecture used for its e-commerce applications.

E-commerce is not just about buying or selling products/services on the Net. It is also about efficiency and effectiveness of doing such transactions over the long haul, which largely is a function of capability to upgrade hardware and software components comprising the organization information infrastructure. Moreover, the organization must also be able to use the latest tools to quantify the responses (feedback) from its customers and be able to assess the time and cost saving of its e-commerce system.

2. Application of modular design principles. The e-commerce infrastructure must be build by self- contained and functionally cohesive system components. Modularity is one of the important characteristics of an open architecture. It enables the functions that change rapidly or evolve over

time be upgraded and changed with minor impact to the remainder of the system. Additionally, modular partitioning of a system appropriately during the design process to isolate functionality makes the system easier to develop, maintain, and modify or upgrade. Modular architectures have the following characteristics:

- *Functionally partitioned into discrete, scalable, and reusable modules consisting of isolated, self-contained functional elements*
- *Rigorous use of disciplined definition of modular interfaces, to include object oriented descriptions of module functionality*
- *Adaptability and ease of change to achieve technology transparency and, to the extent possible, make use of commonly used industry standards for key interfaces*

Designers of e-business systems/applications should group and regroup components that perform a single independent function or single logical task into modules. They should use desirable attributes such as low coupling, high binding (cohesion), and low connectivity to do the grouping required for modularity. Decoupling modules eases development risks and makes future modifications easier. High binding (similarity of tasks performed within the modules) allows for use of identical or like components or for use of a single component to perform multiple functions. Low connectivity (relationship among internal elements of one module to those of another module) is desirable because it reduces design and test complexity [8].

3. Preference for use of open standards for key interfaces within the system. *Key interfaces are those where the technology turnover is rapid on one or both sides of the interface, design risk is high on either side of the interface, and the system elements on one or both sides of the interface exhibit a high failure rate or are very expensive [8]. As mentioned by Zachman architecture is the baseline for managing change. Designation of an interface as key interface in an open architecture means that the preferred implementation would employ an open interface standard (i.e., a widely supported and consensus-based standard) to manage change. This does not mean that the final implementation for every key interface will always use an open standard. There will be times when the best decision is to use a closed interface. This decision is left to the e-commerce development team as part of the open system strategy. Following factors may be considered by the e-commerce development team as they decide whether they should use open standards to define a key interface:*

- *Overall technology strategy. For example, the likelihood that the technologies/engineering for full capability still need to be developed and whether or not the longer-term requirements are stable or addressed as evolving increments. The degree of dependency on rapidly evolving technology and the technology readiness level for the components or items at both ends of an interface is an important consideration for selecting an open standard for the interface*
- *The intensity and magnitude of risks associated with proprietary interface standards.*
- *Need for minimizing integration risks over the life of the system*
- *Need to take advantage of competition throughout the life cycle*
- *Need for design flexibility, modularity, and interface control*
- *Availability, maturity, verification, and accreditation of standards for an interface*
- *Support strategy (e.g., the extent of market acceptance and availability of products that comply with a selected standard)*

The flexibility of a system or its components is measured by the degree to which its architecture or standards are open. Pure (complete) openness is not practical and/or economical in most cases and is not recommended. System designers must focus on reasonable openness

rather than 100% openness to create the architectural flexibility required for e-commerce efficiency and effectiveness. Such flexibility is best maintained through sound systems engineering and management processes that leverage the natural cycle rates of the underlying components throughout the entire system life cycle and architecture-driven modularity of various elements used in a system. The shading and the direction of arrows in Figure 1 depict the preferred type of standards to use for key interfaces in an open architecture [9].

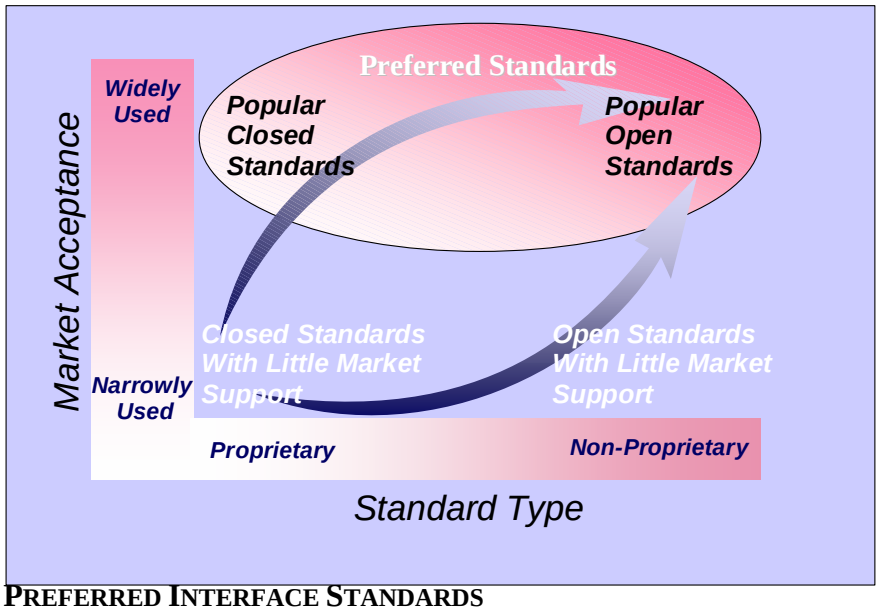

FIGURE 1: PREFERRED INTERFACE STANDARDS

4. Effective interface management. Interface management is the last essential principle for developing and maintaining a viable open architecture. It is needed to maintain rigorous definition of interfaces and ensure openness and viability of the system. Interface management identifies, develops, and maintains the external and internal interfaces necessary for system operations. Every organization conducting e-commerce business needs to put together an interface management plan. An interface management plan is a configuration management plan that documents a system's internal and external interfaces and their requirement specifications; identifies preferred and discretionary interface standards and their profiles; provides justification for selection and procedure for upgrading standards; and describes the certification s and tests applicable to each interface or standard to ensure openness.

The architectural flexibility required for e-commerce is maintained through sufficient control over interfaces and the application of open standards (i.e., consensus-based and widely used commercial standards) to define such interfaces. Sufficient control over interfaces is needed to permit (1) quick and effective communication among stakeholders; (2) rapid configuration of systems and processes; (3) affordable development and supportability through continuous access to multiple sources of supply; and (4) increased adaptability to upgrade and change as new technologies become available or requirements evolve.

II. The Research Methodology

A Modular Open Systems Approach (MOSA) is an integrated business and technical strategy for developing flexible and standards-based architectures to achieve affordable, interoperable, and sustainable systems. As a business strategy, MOSA aims at reducing the total system ownership costs using the latest products and state-of-the-art technologies from multiple sources. Reduction in total ownership cost (TOC) is mainly achieved through lowering the development cycle time, enabled by using COTS (commercial off-the-shelf) products rather than undertaking expensive and complex development projects. A further reduction in TOC is achieved through access to latest technologies from competitive sources enabling an organization to incrementally upgrade a system rather than redesigning the entire system. Additionally, MOSA allows for building more supportable, reliable and maintainable systems resulting in considerable savings in sustainment and operations costs and extension of economic and useful life of a system.
As a technical strategy, MOSA utilizes modular design tenets such as encapsulation, cohesion, self-containment, and high binding to achieve design for change. MOSA also employs widely supported and consensus-based standards for key system interfaces to develop flexible and robust architectures that can easily adapt to changing requirements and technologies.
This paper will focus on business and organizational requirements for implementing the MOSA. Such requirements evaluate the feasibility of using open systems design and establish the necessary conditions for effective utilization of MOSA by an organization. The business requirements for the use of MOSA have been articulated by the Open Systems Joint Task Force (OSJTF), a leading advocate of MOSA in the Department of Defense in a guide for implementing MOSA published by the DoD. This research has used the business indicators identified in the OSJTF guide and has conducted an exploratory research to (1) assess the degree of understanding of modular open systems approach in organizations; (2) identify the obstacles and barriers toward effective MOSA application; and (3) identify the principal business requirements needed for success of MOSA implementation. To this end, a questionnaire was designed and after appropriate face and content validity, and reliability tests was sent to a convenient sample of 170 defense and IT organizations involved in various system development projects. Of the total population surveyed, 105 organizations reported that they were using an open systems strategy to develop systems.

III. Research Findings

Development of an open architecture requires significant decisions about the organization of a system (e.g., partitioning into modular elements/functions), disciplined and precise definition of key interfaces (i.e., the interfaces for which the preferred implementation should use open standards), and continuing market analysis to assess the viability of standards and compliant products. Figure 2 shows the contextual requirements and the principles required for development of affordable and adaptable systems.

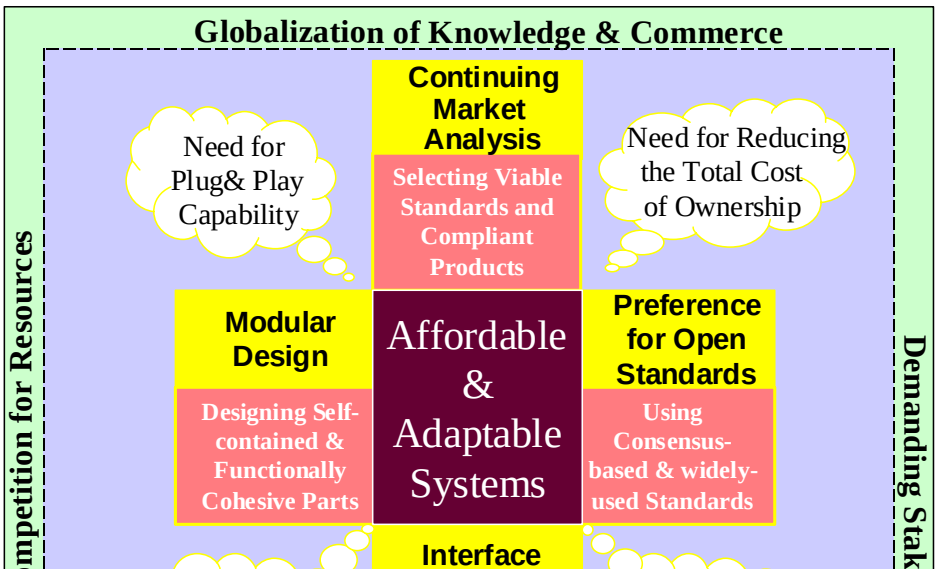

Figure 2: The Open Architecture Framework

As shown in Figure 2, affordability and adaptability are the main purpose for developing an open architecture and constitute the heart of an open system architecture. The authors based on their personal experience and the findings of a survey of more than 150 small and medium sized organizations recommend the application of a "V" systems development strategy for developing open system architectures for EC systems.

B. Open Architecture Requirements:

The above-mentioned principles enable the fulfillment of the main purpose of an open architecture (i.e., affordable and adaptable systems), and are established in response to 4 fundamental needs that comprise the requirements for development of an open architecture. The need for development of an open architecture varies from one organization to the other. But they can be categorized into 4 fundamental business and engineering requirements:

- **Need for plug and play capability.** Organizations can no longer afford to build proprietary systems and components that are unique, and will not interoperate with other systems/components. The dependence on multitude of networks, the pressure from competitors, need for connectivity, and use of commercial products will necessitate development of a robust and flexible architecture. The organization must be able readily assemble and interconnect the systems/components as needed. Using a "mix-and-match" approach, the plug and play capability will construct new systems from the components of existing systems and/or from products/technologies that are widely used and commercially available [8].

- **Need for reducing the total cost of ownership.** The intense competition for resources, the increasing cost of integration, and ever-increasing demand for more efficiency by organization stakeholders have resulted in massive pressure for reducing cost decrease in funding. These conditions impel reduction in the overall cost of ownership for systems, heavy emphasis on outsourcing, and ability to leverage the investment of other firms in new technologies and products, which in turn necessitate incremental system upgrade rather than a total redesign of an existing system.

- **Need for meeting evolving requirements.** Customers demand modules with multifunction components, and more functions per dollar of investment. Moreover, as the

customer and supplier base grows more capacity, functionality, and processing speed will be required to meet the new requirements. Moreover, insertion of new technologies (e.g., new hardware and software, bandwidth, etc.) will also create new requirements, which must be continually and effectively met by the system. An open architecture can deliver the flexibility needed for meeting the evolving needs associated with e-commerce systems.

- **Need for rapid development.** Time to market is of essence for companies heavily involved with e-commerce as well as for those who are still hesitant or have limited e-commerce capability. The globalization of knowledge and commerce and the intense competition necessitate rapid and cost effective development of new systems and modernization of existing ones. Time to market can break or make an organization.

C. The Contextual Environment:

The open architecture environment is characterized by change. The requirements for development of an open architecture are mandated by 4 general environmental characteristics that are currently shaping the 21st organizations [10]. The following paragraphs will take a closer look at each of these general environmental characteristics.

1. Immense technological "Big Bang." The technological breakthroughs that occurred during the last century and the ones that will emerge in the near future are rapidly and drastically changing our lives. The floodgate of this massive change is about to be fully opened and its accelerating speed, enormous intensity, and impacts will soon overwhelm us (21). The emerging paradigm of technological change will be at least 1000 times more powerful than the mechanization technology breakthroughs that happened during the industrial revolution. Next generation technologies under development will change the balance of power and benefit those who can effectively plan, develop and exploit them via flexible architectures.

2. Globalization of Knowledge and commerce. Unlike the past, scientific information is no longer a secured and privately owned secret. Knowledge has become a global free good and is readily available to competitors around the world. The rapid advance and integration of telecommunication and computer technologies, and the standardization efforts within the newly emerged industries has created suitable conditions for proliferation of new technologies and globalization of commerce and competition. Capitalizing on more advanced technology and enabling connectivity to quickly receive and exchange information demand an open EC architecture.

3. Intense competition for resources. Real-time development and production will be the basis for increased competition. In an information dominant battlefield of competition, the systems must be upgraded and reconfigured quickly and affordably. In response, the planning and development cycle must be drastically shortened and systems become open and versatile.

4. Demanding stakeholders. Organizational stakeholders (e.g., stock holders, customers, suppliers, employees, etc.) demand organizations that will be leaner and act like an integrator and consumer of new technologies and systems rather than the sole producer of them. This shift requires a new way of thinking in the organization that must go beyond the current strategic plans and organizational policies. What is needed is a

complete overhaul of the organization information infrastructure and culture. Rather than ornamental and short-term changes, the organization of the future must become a flexible open system that can efficiently and effectively interact with its surrounding environment and rapidly adapt to it.

D. The Proposed Model

The framework and the proposed open systems development model capitalize on the well-known "V" development strategy (Figure 3). The "V" development strategy is suitable for systems that are complex, must be heavily decomposed to effectively design, and most often it is necessary to check that the outputs of a stage not only satisfy the specifications of its inputs, but also meet the requirements of the real world application. The left-hand side of the "V" represents refinement of open system specifications and the right-hand side of the V represents verification and testing. As a result of the feedback loop between processes in both arms of the "V," correctness of each step is verified before proceeding to the next step.

The steps (tasks) proposed in the model are established based on personal consulting works, observations, and experiences of authors with both e-commerce as well as Customer Relationship Management (CRM) in industry and government. In addition, the model has been validated by findings of a survey of more than 150 companies and government agencies. (please see the Appendix) The proposed model and framework should be used as a supplement rather than a substitute for existing e-business models and CRM systems engineering approaches utilized by an organization. In a way, they provide a road map to extend the open architecture beyond information technology applications, and integrate it with e-business and CRM strategies and practices.

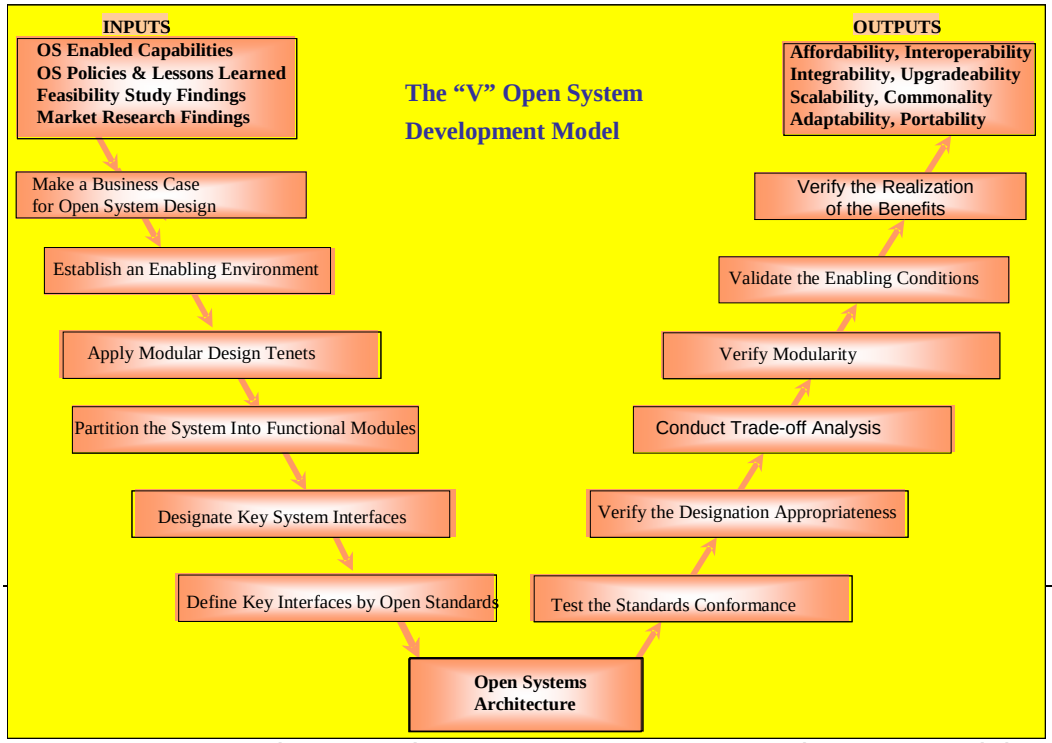

Figure 3: The "V" Open Systems Development Model

The authors provide the following detailed instructions and guidance on how some of these steps

(tasks) should be undertaken:

- Organizations should identify specific capabilities, acquisition objectives, or requirements that can most effectively be enabled by using modular open system architectures. They should be aware that certain capabilities are more quickly and cost effectively realized by open system solutions. Modular and scalable architectures should be the preferred design choice if capabilities must be fielded in time phased increments, and when requirements demands quick integration, interoperability, and reconfiguration of systems and their modules.
- The organizations should also capitalize on flexibility, robustness, and vendor neutrality of open systems and use them as the rationale supporting a chosen acquisition approach (e.g., evolutionary acquisition). The organizations should also use open systems principles identified earlier to determine how the program should be divided into technology spirals and development increments, and how early increments will be integrated or retrofitted with subsequent increments in the most cost effective manner. They should also exploit open systems principles to effectively and affordably organize and connect systems into integrated system-of-systems architectures.
- An important step that must be followed by an organization is that it should not blindly follow an open systems design strategy and must make a business case for using open system architectures. Organizations should preferably use dynamic business case analysis models and apply market research findings to evaluate the appropriateness and feasibility of open systems. The models should take into consideration the changes in technology and threats to evaluate the total life cycle costs of designing systems as open rather than closed systems. The implementation process should describe how the organization will use market research throughout the life of the system to identify emerging standards and compliant products and new technologies to support future technology insertion. The review of technologies and standards should assist the organization the identification of developmental risk areas with consequent impact on test and evaluation efforts. The organization should also conduct market research as part of the system development efforts to assess the availability of open standards to insure that interfaces developed permit exploitation of commercial markets.
- In order to arrive at a system that exhibits open system characteristics, it is critical to have a set of measures or attributes indicating that these characteristics will be present as the system is being developed and when the system is complete. These measures or attributes may be aimed at self-assessment or intended for consideration and use by organization executives, or other responsible or interested parties. The open architecture developers should relate open systems benefits to organization results and objectives. They should use assessment tools and specific metrics to gauge the progress on implementing an open architecture, and ensure timely, efficient, and effective implementation.
- Mismanagement of key interfaces can result in enormous integration and interoperability problems, configuration mismanagement, more complexities in validation and verification tests aimed at ensuring openness; and additional risks related to technology obsolescence and dependency on a sole source of supply throughout the system life cycle. The ensued issues and complexities will be even more drastic in a collaborative or system of systems than in an isolated system because in a collaborative system the interfaces act as a glue that will enable different systems to synergize into a whole greater than sum of the parts. The organization should develop interface management and conformance test plans to ensure that the system and its component modules conform to the external and internal open interfaces allowing plug-and-play of modules, net-centric information exchange, and re-configuration of mission capability in response to new threats and technologies. Such plans must become an integral part of the overall organization change management process. Interface management deals with monitoring the viability of interfaces and architectures and establishing an interface

management plan to update interfaces, assess emerging standards, and abandon obsolete architectures. The interface management plan is part of the configuration management plan and performs the following functions:

- document system's internal and external interfaces and their requirement specifications,
- determine criteria for designating key interfaces,
- identify preferred and discretionary interface standards and their profiles,
- provide justification for selection and procedure for upgrading standards, and
- describe the certifications and tests applicable to each interface or standard.

Conclusions

This paper initially outlined the basic requirements and critical success factors for online commerce. It was discussed that some of the critical factors for promoting a successful online commerce, aside from a well thought out business plan were: flexibility, speed, adaptability, rapid release of products/services, seamless integration of back-office and front-office systems. Next, the paper explained the characteristics of open systems architectures and elaborated on the benefits of such architectures. It was then suggested and discussed in detail that a "V" development strategy would provide adequate flexibility to an organization to implement open systems architectures needed for successful online commerce. Such architectures would provide adaptability, scalability, portability, and interoperability capabilities as well as mix-and-match and plug-and-play abilities, as well as a suitable environment for effective systems integration. The economic benefits of open architecture were also briefly discussed.

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