Architecture Practice Study for C4I Systems Development

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Abstract

The concept of architecture for the development of systems of systems is yet to fully mature. Most organizations currently have a fragmented approach to architecture development. In this paper we address the conduct of architecture practice and propose an overall model for assessing an organization's ability to implement an architectural approach.

1. Introduction

Like most information systems development in large organizations, C4I systems development is challenging the traditional process for acquiring, changing and re-developing information systems. Current information systems development is considered inadequate, lacking in support and unfit to resolve the increased complexities of future systems. Results from thorough examination of past experiences and legacy systems consistently show symptoms that require process innovation and improvement of information technology (IT) practice.

Practitioners and researchers of C4I systems are trying various methods to generate sufficient development capability for evolutionary acquisition of knowledge-based warfighting capability. Some of the noticeable and recognizable work done so far is based on the same concept — architecture [CAWG, 1997 (1)], [Zachman, 1996], [Microsoft, 1999], [SEI, 1999] and [IAWG, 1998].

This paper provides a brief overview of features of C4I systems development, plus research and development efforts in architecture. A comprehensive definition of architecture based on three major roles of architecture is introduced [Chen *et al.*, 1998] to suggest that more attention needs to be paid to the area of architecture practice as a whole. Rationale and management of architecture practice are critical factors in determining the maturity level of an organization's development capability in IT. Increasing complexity of architecture issues in many aspects of C4I systems development necessitates the need to study architecture practice with a strategic intent to manage the complexity rather than focusing on any single architecture product or framework (or approach).

Architecture practice as an important discipline deserves more attention and has great potential in improving IT development capability of large organizations.

Specifically, this paper discusses an architecture practice proposed for the Australian Defence Organization (ADO), which can accommodate multiple architecture frameworks or approaches for different purposes and provide adequate coordination by clarifying and rationalizing the interrelationship amongst them within a well-defined practice context.

2. Features of C4I Systems Development

The level of sophistication of information-based C4I capability is determined by what advanced technology is used and how C4I business is supported in terms of efficiency and effectiveness in information and knowledge processes, in other words, how smartly the technology is used for C4I. Successful C4I systems development requires the organization to be capable of dealing with the following challenging issues.

Evolutionary Development

Evolutionary development of C4I information-based capability is the reality facing defence organizations. One of the main challenges in such development is integration or interoperability since individual C4I systems are often developed by different people using different technologies. C4I interoperability requires a unifying framework and a body of definitive implementation guidance. As stated in [NRC, 1999], achieving C4I interoperability is largely a matter of management, design, and implementation discipline rather than of resolving technical issues.

Systems of Systems (SOS)

Strategic thinking and system engineering for C4I are based on the concept of SOS, which are large, complex, and distributed across organizational, program, and geographical boundaries. Thus, a clear understanding of SOS development issues is crucial not only for current system development but also for planning the future organization. The ability to deal with SOS for most large organizations is not well developed.

Integrating C4ISR Capability Development with IT Practice

An important measurement of development capability maturity for C4I systems is the integration of the C4ISR capability development process and organization’s IT practice. The requirements for IT development capability for C4ISR are expected at a high level although they have not been studied specifically and systematically. For instance, IT capability planning becomes an important part of military campaign design in order to ensure that the commander is fully aware of the availability of IT capability and interoperability in the course of military operations

Body of Knowledge for C4I Systems Development

C4I systems development is related to many different areas of the defence organization. Knowledge used across these areas is fundamental to effective creation, description, construction, integration, management, reuse and evolution of capability. Knowledge is an asset of the organization and its effective generation and management are important aspects of IT development capability.

Evolutionary development of C4I systems requires many activities (both reasoning and synthesizing) to be undertaken in a complex context. These activities lead to a series of decisions, including: engineering and technical decisions, project management decisions, military operation business decisions and other types of decisions representing the full range of stakeholders in the development process and end-application. Each decision involves an understanding of the problem to be solved and the rationale for the suggested solution. It is this body of knowledge that provides a context for reasoning and determines largely whether the plan and subsequent development are to be successful or not. As a result, it becomes necessary to develop a comprehensive set of support environments for decision making in different areas related to C4I systems development and for sustaining the body of knowledge.

Past experience in C4I systems development shows that problems and difficulties are mainly caused by an organization’s inadequate development capability in IT practice. This capability is determined traditionally by vendor-based practice or technical solutions, which have proved to be limited in terms of the power required to overcome the difficulties. Although development of various technologies and tools can improve development capability to a certain extent, significant maturation relies on an understanding from the organization itself on what IT development capability is needed and what changes should be introduced in the culture and management of IT practice.

Many solutions proposed for enhancing IT development capability in the area of C4I systems development are related to the concept of architecture. It is now recognized that the most promising solution is to generate and adopt an enterprise-wide architectural approach for the whole IT practice of the organization [CAWG, 1997 (1)], [Zachman, 1996], and [Meta Group, 1999].

3. From Architecture to Architecture Practice

The concept of “architecture” is not new and has become a mixture of hopes, confusion, interests and disappointments for many large organizations due to a lack of consensus and over use of architecture for different interests. The complexity of architecture within large organizations has been rapidly increasing for two reasons. First, there is a diversity of architecture products associated with various architecture definitions introduced for different purposes [CAWG, 1997 (1)], [Martin *et al.*, 1994], [Bass *et al.*, 1998], [Zachman, 1996], [Microsoft, 1999], [SEI, 1999], [OIC, 1997], [IAWG, 1998], [ISO 1996], [Pirokla, 1995], [DISA, 1996], and [El-Sakka *et al.*, 1999]; and secondly, a complicated context of mixed development scenarios exist as depicted in Figure 1.

Single and Stand-Alone System Development

This type of system development is what is traditionally used to develop IT applications in isolation to other systems. The architecture issues needed to support the development of these applications are; data architecture, function architecture, programming architecture, etc. These architectures are specifically developed from scratch for each of these single applications. They are usually stand-alone, they share neither data nor functionality – they do not interface with other systems.

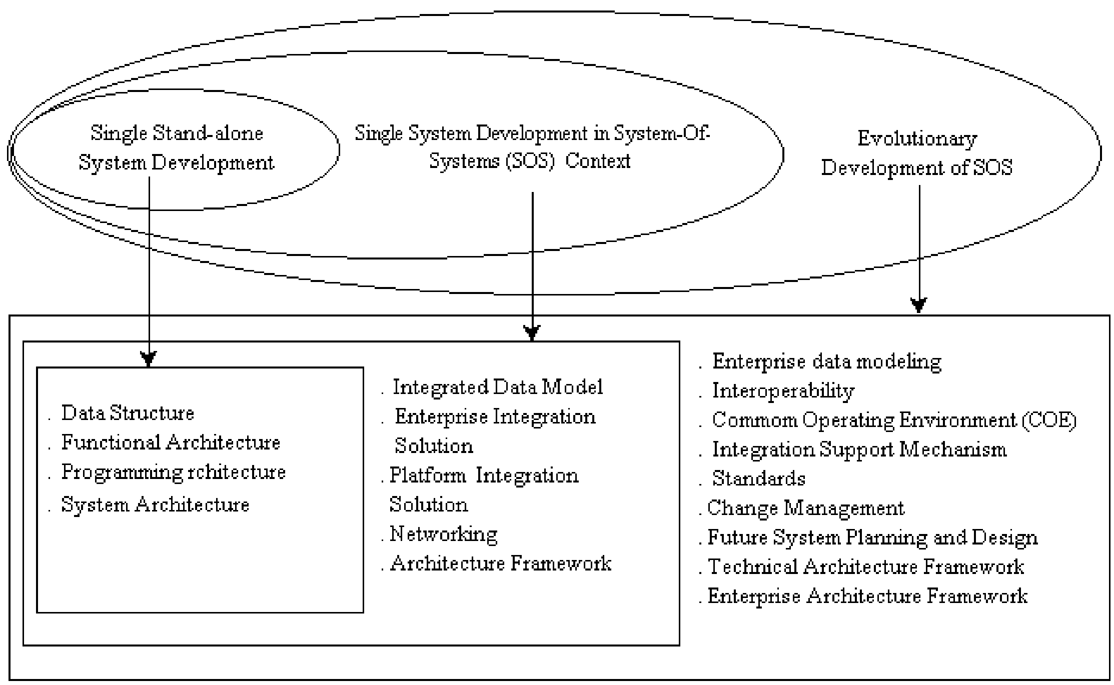

Figure 1. – Increase in Complexity of Architecture Issues

Single System Development in SOS Context

This type of system development is what is traditionally used to develop systems with limited connections to other systems. The architecture issues needed to support the development of such systems are the architecture issues of single systems and additional architecture issues such as; integrated data model, enterprise integration solution, platform integration solution, networking, etc. The increase in the number and complexity of architecture issues has become evident when such systems must interface with either the data or function of another system.

Evolutionary Development of System of Systems (SOS)

A system of systems is a super-system, which consists of a number of components. Each component is a system in its own right. The components collectively constitute the super–system which can perform unique functions, the individual components can not perform on their own.

The architecture issues needed to support the development of SOS cover the architecture issues of the previous two types of systems and additional architecture issues such as; enterprise data model, interoperability, common operating environment (COE), standards, technical architecture, etc. The increased number and complexity of architecture issues is evident when SOS is required to communicate with each and every system in the local and global domains with a high level of interoperability.

Under different development scenarios, therefore, interests, focuses and solutions in architecture vary as different stakeholders make contributions to different aspects of the IT development capability with different concerns or responsibilities. By examining various architecture definitions and the context in which they are introduced, the authors have developed an inclusive and comprehensive explanation of the concept "architecture" [Chen *et al*, 1998], and [El-Sakka *et al.*, 1999].

Fundamentally speaking, **Architecture** of a system or an object is defined as knowledge about that system, described and represented by a set of views, which collectively reflect the concerns and the requirements of the stakeholders of that system. Architecture can be viewed as having three distinct features/roles: being a blueprint – basis for acquiring a new system, being a current picture – basis for understanding an existing system, and being a roadmap – basis for supporting realization of the first two features.

Architecture practice is an emerging and fundamental discipline, which has the potential to improve IT development capability of large organizations by addressing systematically the principles of development, management and use of architecture. Through such a practice various organizational knowledge and systems knowledge may be engineered for a diversity of purposes.

Since architecture practice for most large organizations is not well planned and managed, the potential of architecture claimed by using many architectural approaches is not achievable. This situation arises due to three common problems appearing in most architecture activities, that is, *incompleteness*, *inconsistency* and *confusion*. It is not surprising that some large organizations or certain business domains, like C4I, may even face more chaotic situations due to the increasing complexity of architecture issues.

The complexity of architecture practice increases as the practice covers more areas or involves more different activities. There are a number of factors that contribute to the increase in complexity.

- Diversity of activities

Architecture issues addressed in different activities are classified as shown in Figure 2 into three main sectors in terms of their nature and outcomes.

- Interrelationship amongst activities and outcomes

Detailed examination of architecture issues reveals that the increasing complexity is directly caused by interrelationships amongst architecture activities and their outcomes. Either the roles of individual architectures or contributions made by architecture activities have impact on other products or activities in IT practice. There is no means to clarify such interrelationships in existing IT discipline.

Sectors	Examples	Features	Issues
Architecture Frameworks (approaches)	• Zachman • C4ISR AF • Microsoft Solution • RM-ODP • Info. Tech. Architecture • etc	Guiding architecture construction processes	Coordination amongst multiple frameworks
Descriptive representation	• Software arch. • Enterprise arch. • System arch. • Arch. Repository • etc	Architecture descriptive products	Architecture product management
Supporting environment	• Tech. arch. frmwk. • COE • Standards/Guideline • Interoperability spec. • Reference arch. • etc	Architecture supporting products	

Figure 2. Diversity of architecture issues

- Continuity and concurrency of activities

Continuity of architecture activities varies according to their nature. Traditional architecting practice is characterized by an architect's work, ending before implementation commences. It is basically a project-wide practice. Technical architecture frameworks, however, require on-going efforts to maintain their validity. Concurrency of activities is evident as projects are usually carried out in parallel for SOS development. Thus, the time dimension further complicates architecture issues.

- Number of people involved in the practice

Architecture practice is an on-going process of a community with people coming and going perhaps working for different agencies and vendors. In such a community of practice, facilitating communications, knowledge sharing and integration, knowledge management and reuse, and knowledge preservation and evolution is methodologically essential for large organizations.

- Mixture of static and dynamic products

Architecture activities of individuals require limited management since they often produce their own products that are either static (such as design) or dynamic (living documents such as technical architecture frameworks). However, architecture practice needs a significant amount of organization-wide management and coordination of activities and products. Evolution of architecture products is another challenge for many individual architecture activities.

A previous paper by the authors has [Chen *et al*, 1998] shown that the context of architecture development provides a basis for an organization to examine and rationalize its IT development capability.

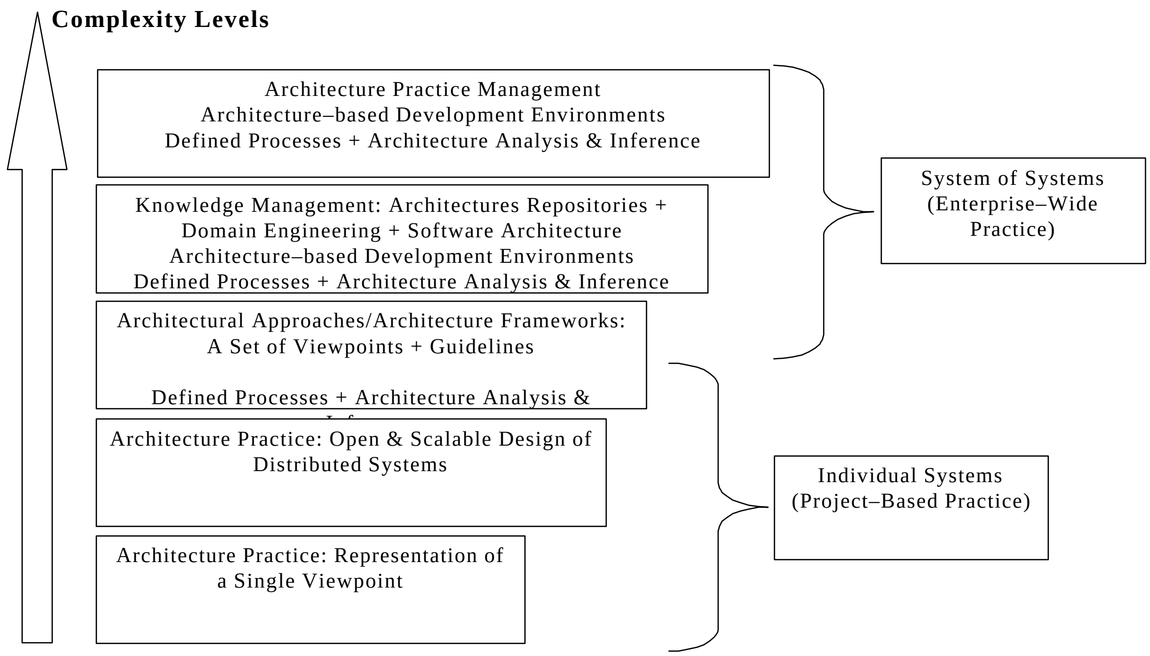

Figure 3. Complexity of Architecture Practice

A systematic study of architecture practice should include: 1) architecture products; 2) processes or methods to produce products, and 3) supporting environments that make processes and methods work more effectively and efficiently. Thus, architecture practice studies should address the rationale and management of the practice, and also strategies that the organization might adopt to improve its IT development capability.

It is important to distinguish architecture practice from most architecture frameworks or approaches such as Zachman Framework, Microsoft Solution Framework, TOGAF and the C4ISR Architecture Framework. An architecture framework or an architectural approach usually suggests a set of principles from specific viewpoints for certain architecture-related activities which are indeed part of architecture practice. Architecture practice operates in an enterprise-wide context where multiple architecture frameworks or approaches can be used for different aspects of IT practice. It can help the organization to coordinate, integrate and manage all architecture-related activities.

We see architecture practice as a “science” supporting IT applications and future business development, which has relevance to many other disciplines including computing, information systems, knowledge engineering and organization studies. Therefore, studies of architecture require a methodology to address the following main issues:

- What is the rationale behind architecture practice?
- How is it related to the IT development capability required by an organization?

- How can architecture practice be planned, coordinated and managed in order to achieve the potential of the architecture concept?
- What kind of architecture practice supporting environments should be developed for a particular organization?
- How is architecture practice related to other relevant disciplines?

In developing a common understanding of architecture issues it can be shown that shifting focus from architecture to architecture practice results in the disappearance of some of the confusion related to the definition of architecture and also provides a context framework for relating different architecture products and processes.

4. Architecture Practice Requirements for C4I Systems Development

The US DoD has led architecture practice for C4ISR. Its experience and achievements have provided a sound background and rich information sources for researchers and developers in C4I systems development.

The concept of architecture has been widely used in dealing with the main features of C4I systems development. The ability to define and analyze system designs through architecture; to specify and analyze changes at the architecture level, and; to create and maintain architecture as corporate assets, is highly desirable for the organization to succeed in evolution of its IT capability. To carry out such a wide range of activities, an integrated and well-planned architecture practice is required.

One of the most important benefits from studying the US DoD's architecture practice is it provides a good basis for understanding the limitations of most current architecture frameworks or approaches.

Enterprise-Wide Challenge

Architecture issues for C4I systems development are challenging the defence organization as whole. A combined or integrated effort to reach overall guidance for architecture practice is not only necessary but also critical to success. The resolution of this challenge can neither be any single architecture framework or a specific architecture solution. They must be generated from and operated within a well-guided enterprise architecture practice.

Improved IT Development Capability

The level of IT development capability is determined by the ability of many different areas of IT practice, including business and technology planning, design, acquisition, implementation, maintenance and evolution. Current practice involves various stakeholders and developers handling not only products but also processes. Some architecture frameworks show the potential to improve the status quo. Architecture practice has a much broader coverage and can provide a meaningful context for the organization to examine and enhance its abilities. Modeling and simulation are highly desirable activities that need to be performed to ensure the delivery of effective and robust

C4ISR systems. These activities need to be well integrated and supported by the architecture practice which in turn form the backbone of the IT development capability.

Operational Architecture

An important concept used in the US DoD's architecture practice is "Operational Architecture" (OA). It is this concept that explains why many other architecture approaches cannot meet the requirements of C4I systems development. The core business capability of the defence organization is built on the concept of "Operation" which characterizes the requirements of IT capability in terms of qualities in time, interoperability, security and other dynamic features. The operational architecture is a key means used to not only plan military operations but also to outline the initial requirements of IT capability required for the mission.

Knowledge Evolution

It is important for defence organizations to recognize the value of systematic modelling as a way to establish and take advantage of an organization's experience and best practice. Information-based capability development relies heavily on "Software" that is unique among engineering disciplines in its rapid pace of evolution. Any approach to domain modelling or software reuse that ignores evolution is bound to fail. Well-planned and well-managed architecture practice can improve knowledge acquisition of the organization in its IT practice [El-Sakka *et al.*, 1999]. While individual architecture-related activities may support different stages of knowledge acquisition, a comprehensive architecture practice can help to achieve an integrated architecture business cycle (ABC) (as illustrated in figure 4). An ABC facilitates organization knowledge preservation by integrating architecture-related activities and providing support across all stages of the acquisition cycle, including creation, description, synchronization, storage and reuse.

In summary, architecture practice for C4I systems should achieve the following main goals:

- Support exploitation of the concept of "Operation", in particular Joint Operations;
- Support campaign design processes from force capability to IT support capability;
- Achieve a practice with overall guidance for all of the organization;
- Improve knowledge acquisition and management in all stages of capability development; and
- Achieve an architecture practice supporting environment — an information management platform, including functions for all levels and domains of C4I.

5. Architecture Practice Recommended to the ADO

The architecture practice shown in Figure 4 has four main considerations:

- To develop a framework to examine and improve IT development capability in combination with C4I capability development;
- To engineer knowledge of information systems into organizational assets;
- To achieve a framework to integrate and manage IT practice disciplines; and

- To conduct the practice with clear strategic directions for defining, developing and managing architecture products, architecture construction processes and supporting environments.

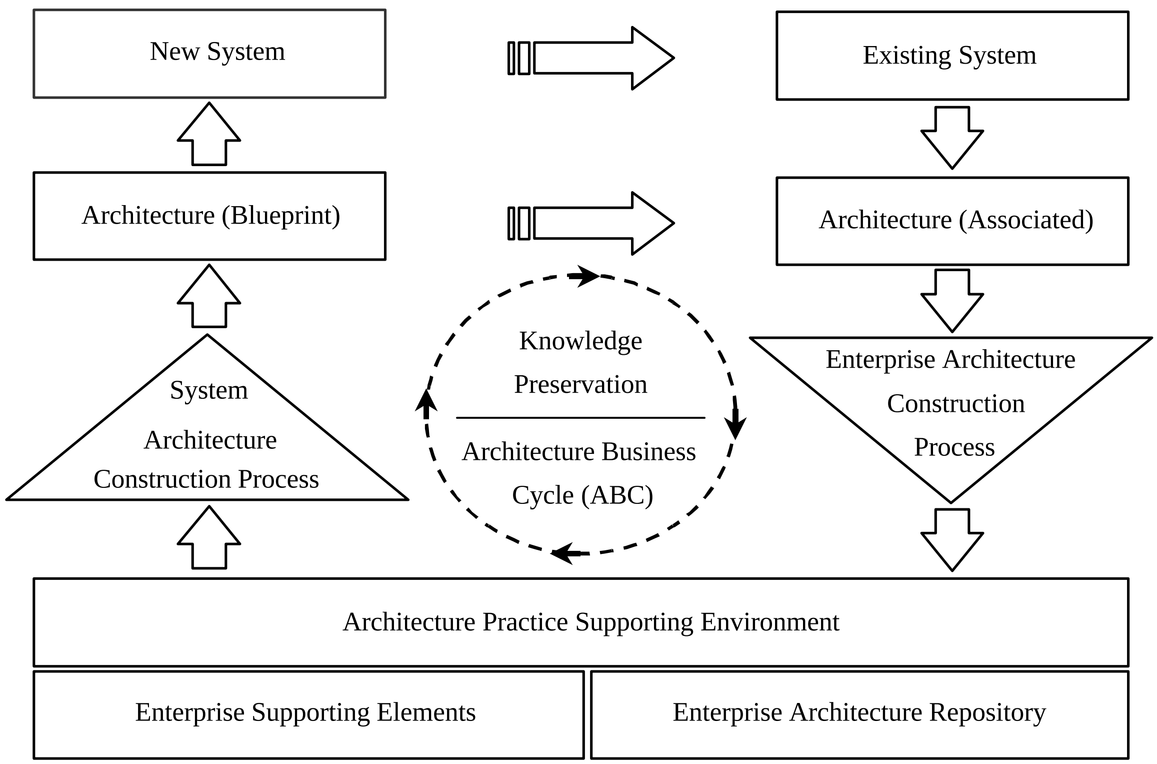

Figure 4. Recommended Architecture Practice

This illustrated architecture practice is based on a comprehensive understanding achieved through: 1) investigating the roles of architecture; 2) studying the US DoD's architecture practice; and 3) comparing different architecture methodologies. It can be used as a generic process guide to large organizations and has been suggested as a starting point to plan and improve architecture practice for the ADO.

In Figure 4, the proposed architecture practice has two architecture construction processes: one to construct blueprints and the other to construct a picture. Both these processes require use of suitable architecture frameworks or approaches. In the current practice of US DoD, for example, the C4ISR Architecture Framework [CAWG, 1997 (1)] is mandated to be used, first, to develop architectures (blueprint) in the system architecture construction process (SACP) for all future C4ISR systems.

Studying other initiatives of the US DoD in architecture-related areas [DARPA, 1997], [LM, 1996] and [Horowitz, 1994], we believe that the system architecture construction process is not isolated from other components. The universal references, such as JTA, JOA, LISI, CADM, etc developed by US DoD, are typical examples of the enterprise supporting elements for C4I systems development. By including the enterprise architecture construction process for establishing the current picture of existing IT capability, the recommended practice sets the context in more complete terms for enterprise knowledge preservation and reuse.

The main differences between the recommended practice and architectural approaches (or architecture frameworks) are:

- Most architectural approaches are developed and used to guide architecture-related activities focusing on certain aspects of architecture practice.
- Architecture practice focuses on the principles of context management for all architecture-related products, approaches, issues and activities. It can provide rational suggestions and guidance on how to choose architecture frameworks and how to develop the elements for the supporting environment and systems architectures.

One of the main features of architecture practice is provision of a well-defined context for developers to plan and conduct their work so that they make best use of the resources generated by others. The practice facilitates coordination among different frameworks as far as they can be tailored to fit into the context.

The enterprise architecture construction process (EACP) helps to achieve organizational knowledge preservation. This process is not considered by the traditional software engineering disciplines, which basically guide developers in developing a specific system. Such guidance is challenged by the reality of the evolutionary development of C4I systems since it fails to distinguish between the organization’s long-term interests in acquiring IT capability and vendor’s or project-based interests.

The Joint C4ISR Architecture Planning/Analysis System (JCAPS) of the US DoD provides some insights into how to plan and develop an architecture practice supporting environment. This environment provides different interface elements or services to different areas of capability development.

The interface elements (services) associated with functional areas (users) share and use the same information and knowledge resources created by different agencies in various architecture-related activities. In other words, different sets of supporting functions based on the same resources can be developed for different application scenarios.

The Architecture Practice Supporting Environment (APSE) is at the centre of architecture practice. Supporting elements and the repository can be integrated to provide accessibility and functions for architecture planning and analysis across elements or resources. Further work will address the design and development of viewpoints to be supported by APSE.

The Enterprise (systems) Architecture Repository (EAR) is a store of the information that is generated by the EACP. It is always a valid picture of existing IT capability. This information differs from the system architecture (blueprint) generated using different methods or representations before implementation. It is represented in a synchronized format by using a consistent notation. The notation is used to capture only the necessary information and to reference other associated resources including the blueprint if it is not kept as part of EAR.

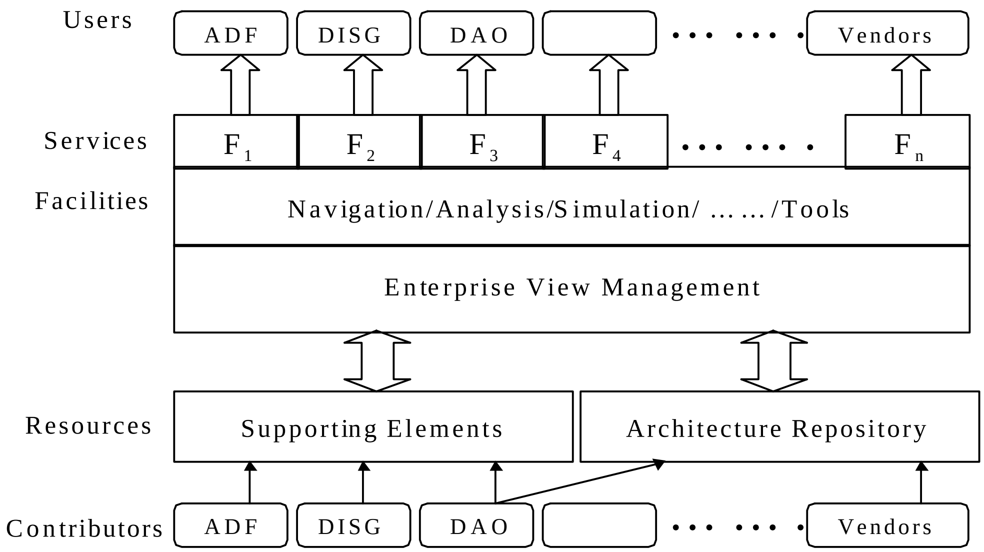

Figure 5. The recommended APSE to the ADO

Is the cost of conducting the EACP too high? The answer is "it varies'" depending on the notation used and process defined. A current picture about existing systems has to be available for future development.

The importance of using a supporting environment can be justified by examining those features of C4I systems development that can be addressed by the recommended practice.

- Evolutionary development will change from a chaotic practice with no adequate support into a manageable process. Interoperability will be addressed through using architecture products that are integrated into and accessible by the supporting environment;
- IT development capability will be enhanced by adopting suitable architecture frameworks for SACP. The enterprise architecture repository will act as a current picture and the enterprise supporting elements as a roadmap so enabling the organization to deal with SOS. The supporting environment should make all knowledge about SOS available and provide useful functions, such as simulation and modelling, to support the SACP.
- Integration of functions and resources in related areas of capability development becomes achievable. In the recommended practice, all relevant agencies should make contributions to the supporting environment and also have responsibilities to maintain validity.
- Support to knowledge acquisition, management and evolution [El-Sakka *et al.*, 1999] will help the organization to preserve its intellectual capital and operate its business more efficiently and cost-effectively.

Therefore, the benefits of studying architecture practice are:

- Achieve a better and more comprehensive understanding of what the architecture practice is required to deliver against the expectation of the organization in IT development capability;
- Through life support for C4I systems as an emerging and important capability of the Defence organization;
- Improve organizational knowledge acquisition and ensure better reuse.

6. Architecture Practice Maturity (APM)

Architecture practice is important and has great potential. It must be realized, however, that carrying out isolated architecture-related activities with no plan is not enough to ensure successful architecture practice.

Architecture practice maturity, generally speaking, is determined by two factors: coverage and maturity of individual elements and activities in the practice. As is observed in Figure 3, architecture practice maturity is related to its complexity. A high-level of maturity of architecture practice involves a high-level of complexity. A high-level of complexity in architecture practice, however, cannot guarantee a high-level of maturity since the maturity levels of individual efforts, products, management and coordination are all important factors.

No sufficient and systematic study has been undertaken to address the concept of APM. An effort in classifying architecture practice maturity levels made by the Meta Group [Meta Group, 1999] through using SEI's model is interesting but only covers certain aspects, mainly the enterprise-wide technical architecture (EWTA) and a product called "repository".

The philosophies used to improve architecture practice could be different from one organization to another. In order to reach the main goal of architecture practice, however, certain issues and challenges are common to most large organizations.

- Strategic planning and management decisions;
- Defining the context of practice;
- Choosing or developing suitable frameworks and approaches;
- Defining and developing the APSE including the supporting elements.

The rapid growth of architecture practice in large organizations will be a noticeable trend in the first decade of the next century [Meta Group, 1999]. This is challenging both researchers and practitioners in terms of achieving a better practice. Questions like why and how architecture practice should grow need to be addressed from many different viewpoints including science, technology and management.

For C4I systems development, however, the ability to handle the concept of "operation" at various levels of the military hierarchy for different mission-oriented operations distinguish its supporting environment from other general IT architecture practice supporting environments.

Defining a number of important concepts such as force specifications and an operation reference architecture in order to manage the body of knowledge associated with defence operations is a necessary step towards successful integration of the C4I capability development and IT practice. Without successful development of adequate architecture products associated with these concepts, architecture practice will not mature.

Architecture practice is not and should not be totally outsourced although some activities may be carried out by external players. The extent to which architecture practice may be outsourced is debatable and will depend on the characteristics of the organization. C4I systems acquisition almost always involves industry. Thus, guiding and monitoring the vendor's architecture activities must be addressed and implemented through SACP and APSE.

Planning and rationalizing architecture practice are not easy tasks. Architecture practice maturity is a challenging issue for large organizations as well industry. If the opportunities for architecture practice are realized by both organizations and industry, then there will be a significant change in the culture and process of IT practice. The change should lead to a more manageable development environment.

7. Conclusions

C4I systems development requires Defence organizations to pay more attention to their architecture practice rather than only individual architecture products. Without a sophisticated understanding and effective management of architecture practice, it is hard for an organization to achieve a high level of IT development capability. It should be appreciated that many individual architecture products or architectural approaches can be developed to address certain aspects of architecture practice. A combination of individual efforts and effective coordination amongst these efforts is important and must be achieved through well-planned and well-managed architecture practice. It is only well-planned and well-managed architecture practice that can realize the full potential of architecture.

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