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A Flexible Approach to Realize an Enterprise Architecture

Ronald E. Giachetti [a*]

Department of Systems Engineering, Naval Postgraduate School, Monterey, CA USA

Abstract

A desired to-be enterprise architecture is realized through many individual projects that incrementally bring the enterprise toward the target enterprise architecture. There are many alternatives projects and the problem is how to decide among the alternatives given budget and time constraints. This paper presents a real options framework to plan a portfolio of projects to realize a target enterprise architecture. Using DoDAF, we describe a method for defining projects as a collection of compound real options. A switching model is used with Monte Carlo simulation to determine the capability phasing view of DoDAF v2.0. We present a case study of a small defense contractor to illustrate our approach. The model and method contributes a means to value a portfolio of projects to realize an enterprise architecture. The motivation for this research is the development of systems engineering tools to help the Department of Defense realize their net-centric transformation to have a more effective and efficient war-fighting capabilities.

Keywords: Enterprise architecture; real options; DoDAF; system flexibility; and enterprise systems.

1. Introduction

The value of an enterprise is significantly influenced by its architecture. Enterprise architecture defines the structure of the enterprise in terms of its structure and form [1]. The architecture dictates to a large extent the capabilities of the enterprise and its behavior. Designing an enterprise, or enterprise engineering, is a systems engineer approach to determining the needed enterprise capabilities and designing the organization, processes, information, and technologies in the enterprise to provide those capabilities. The design of enterprise architecture almost never starts with a blank sheet of paper, but

* Corresponding author. Tel.: +1-831-656-2670.
E-mail address: regiache@nps.edu .

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instead involves the transformation of the enterprise from the as-is system architecture to the to-be system architecture. Moreover, this transformation takes place over the span of many years, and for some very large enterprises they may be constantly changing because they must survive and adapt in a constantly changing environment [1, 2]. Planning enterprise transformation is difficult in part due to the external and internal uncertainty faced by the organization as well as the changes that can be expected to the vision, goals, and enterprise situation that can be expected as the enterprise undergoes transformation. This calls for a flexible and adaptive approach to defining the enterprise transformation plan and to executing it. Such an architectural design process can provide greater value through the potential to avoid risks and simultaneously take advantage of beneficial opportunities as they arise. In this paper, we formulate the enterprise architecture design problem as a planning problem, where management, given limited resources, must decide upon a portfolio of projects to transform the enterprise to the target architectural state. We do the planning within the DoDAF framework [3, 4], which defines the architectural views and data definitions to describe an enterprise architecture. To define a transformation plan for the enterprise, we focus on individual projects that deliver systems, system components, and their integration in order to deliver the target capabilities. The systems are defined by the systems view and the capabilities by the capability view. Our framework derives the capability phasing view (CV-3) of DoDAF v2.0.

1.1. Real options

The concept of real options is taken from financial options on which they are based. Real options allow the holder of the option to exercise the option if conditions are favorable, but the holder is not obligated to exercise the option if conditions are unfavorable [5]. Consequently, the value of options is they allow for the upside potential while limiting the downside risk. Options only have value in the face of uncertainty and when that uncertainty is expected to be resolved before all the investment decisions must be made. This situation is what is faced by those planning enterprise transformation. The target enterprise architecture is brought into service incrementally as systems are developed, brought online, and integrated. During the enterprise transformation, the uncertainty is due to the value of each project, which depends on whether the project is successful, and if so, then by how much. Project success is only apparent after the project starts and progresses. A real options valuation considers the fact that decisions are made sequentially and the decision maker will use all available information at the time the decision is made.

Real options are based on the valuation of the underlying asset whose value is modeled as a stochastic process. In finance, the underlying asset is a tradeable stock and the stochastic process is an extension of the historic volatility and trend of the stock using Brownian motion. In finance, the Black-Scholes equation is used to value call and put options [5]. For real options, selection of the underlying asset is less clear, identifying the volatility is more difficult, and there are several alternative approaches to model the stochastic process. Formulating architecture design in the context of real options allows valuation of architectural project options that allows for both risk reduction and the possibility of exploiting upside potential if it should arise.

1.2. Related Work

Real options can be either on the projects to realize a system or built into the architecture or design of a system [6]. Real options on projects have been used in infrastructure projects and in projects that naturally include phased decision making. Herath and Park [7] present a compound real options framework to value sequential options for infrastructure projects. Wu et al. [8] develop a real options model for ERP investment that involves traditional options of delay, pilot study, and growth options. Several authors have investigated real options in system architectures. Examples of this work include [9, 10].

Our work is part of the stream of research of real options on projects. What distinguishes our work is that we model a portfolio of real options which captures the interdependency that naturally exists between enterprise architecture options. We do this by building on the switching model of Brosch [11]. Our main point of departure is that we use Monte Carlo simulation because the stochastic dynamic programming approach of Brosch is not tractable except for small problems [12].

2. Enterprise Transformation Planning Model

Figure 1 illustrates the problem we are addressing. Given a set of projects, what portfolio of projects should be selected to transform the enterprise from the as-is to the to-be enterprise architecture? The resulting plan provides the capability phasing view (CV-3) in DoDAF. The model assumes that a vision of the to-be enterprise architecture is available and modeled in DoDAF views of AV-1, CV-1, and CV-2. The first step is to map the desired capabilities into one or more projects that can provide that capability. Here a project will deliver one or more capabilities through either a materiel solution or by changing the existing system in some fashion. In our real options framework, the projects are the underlying assets whose cash flow is modeled as a stochastic variable with a known volatility. A project cash flow is the benefits and capabilities provided measured in dollar terms minus the costs of the project. The expected value of the cash flow is estimated for year 1 via traditional cost and benefit analysis. The volatility of the cash flow is measured as the standard deviation per time period for the project. In practice, the volatility would likely be estimated by subject matter experts based on prior projects of similar type, size, and scope.

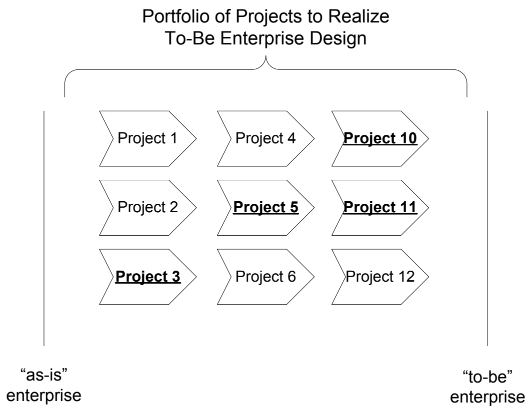

Fig. 1. Generation of CV-3 from multiple alternatives

The projects being executed as part of the enterprise transformation will likely be interdependent on each other. Project interdependencies arise due to the use of common resources, benefits derived from the projects, or technical considerations [13]. The interdependencies can result in either mutually exclusive projects, contingent projects, or a correlation between project success or failure. In the mathematical model we represent mutually exclusive project with constraints, contingent projects as compound real options, and we model all other interdependencies as a correlation between the cash flows of project x and project y. The correlation may be positive or negative and ranges between -1 and 1.

The real option switching model is a stochastic mathematical model that finds the optimal sequence of project investment decisions to maximize the total net present value of the project portfolio over the planning horizon. In the model, real options on projects are represented as different project states that can be switched between. Let a_I denote the option to operate the project in state *i*. The definitions of state *i* can be done so as to represent various options on a project including compound options to postpone, expand, or abandon. We let a_I denote the default operation mode of postponing investment. Initially, every project is in mode a_I. The other states can be defined to represent different options. For example, we could define a_2 to denote the operation mode of a pilot project and a_3 to denote investment in a full scale deployment.

The decision is the investment to make in each project in each time period. Let $x_{ptsaa'}$ denote the binary decision variable of whether to switch from project state a to state a' for project p in time period t and scenario s, where the scenario indicates when the stochastic variable has moved up or down. In our model, cash flow is path dependent because budget availability depends on the scenario history and also the availability of compound options depends on previous investments. Further details of the mathematical model are left out for purposes of brevity.

The model is a stochastic dynamic program, which is known to suffer from state-space explosion that makes this class of problems intractable for any but trivial problems [13]. To overcome the computational complexity, we use Monte Carlo simulation to sample paths for each cash flow. The random variables for the uncertain cash flows are generated according to the correlation matrix using the method of Iman and Conover [14] which generates a set of correlated random numbers. For each cash flow generated by the Monte Carlo simulation, we use a mathematical model to do the dynamic programming to generate the optimal project plan. Then we analyze the results for many simulation runs to devise the preferred decision strategy. Solution of the model determines which projects, options, and time period to invest in each project. In this way, the model generates DoDAF's capability phasing viewpoint (CV-3).

3. Illustrative Example

We present a case study to illustrate the enterprise transformation framework. ABC company is a small and medium-sized defense contractor located in Florida. It is a low-volume and high-mix manufacturer, performing the design, development, and system integration for electro-mechanical systems. The company also has a growing capability for research and development (R&D) including R&D under contract to larger companies. The company's revenues stand at approximately \$15M annually, which they expect to grow to \$50M over the next five years through a strategy of further developing and exploiting their R&D capabilities. They envision an enterprise that has a more visible role in the early phases of defense system development and consequently a larger part of the value chain. Management has identified a strategy for achieving this growth and are concerned about obstacles that may prevent the fundamental changes to transform the company. The strategy includes achieving greater efficiency of operations, better integration of internal systems so they can have better coordination of activities, and better integration with customers in order to work in a more open, collaborative environment. The projects identified involves IT infrastructure investment, enterprise systems investment, reorganization investment, and training investment. Table 1 shows the main input data to the model for the projects. The planning horizon is five years and for each year a limited budget is available for investing in projects. Not shown is the correlation matrix for the five projects that was used to generate the random variables for project value. The starting value of each project is given in Table 1 as initial value.

Correlated random numbers were generated to simulation possible cash flows for each of the projects. 100 Monte Carlo simulations were performed, each simulation taking approximately 2-3 minutes. A transformation plan is developed by running the simulations, using decision heuristics to select a portfolio for year 1, repeating Monte Carlo for the remaining years, and continuing the process until a portfolio of projects is derived for the entire planning horizon.

Table 1. Five projects with three switching options each

		Project Option Description	Initial Investment			Initial Value
			a_1	a_2	a_3	
P1	a_1	Maintain current organization of functional groups	0	0.8	1.2	4
	a_2	Reorganize technical departments into program groups	0.2	0	0.2	
	a_3	Expand reorganization to marketing and other departments	0.3	0.1	0	
P2	a_1	Delay	0	0.6	0.7	0.35
	a_2	COTS – Local	0	0	0.2	
	a_3	Option for HR, CRM, and ERP; i.e., growth	0.2	0.1	0	
P3	a_1	Delay	0	0.45	0.55	0.3
	a_2	SolidWorks upgrade for FEA/Thermal Analysis	0.05	0	0.08	
	a_3	Pro-E	0.05	0.05	0	
P4	a_1	Delay	0	0.76	1	0.6
	a_2	ADP-EZ Payroll	0.1	0	0.15	
	a_3	ADP-EZ Labor	0.1	0.1	0	
P5	a_1	Delay	0	0.2	0.45	0.1
	a_2	DOORS requirement management tool	0.05	0	0.22	
	a_3	CORE requirement management tool	0.05	0.4		

Figure 2a shows the final system state at the end of the transformation planning horizon. In all scenarios, Project 1 is in state 3. Other than this project, the final state of the other projects depends on the history of the stochastic variable. In other words, the optimal decision depends on how the future uncertainty unfolds, which is the main point of the real options framework that decisions depend on how the uncertainty is resolved. Figure 2b shows the distribution of value at the end of the transformation planning horizon, assuming optimal decisions are made. The model can help decision makers by highlighting a strategy to fund projects on a year-by-year basis.

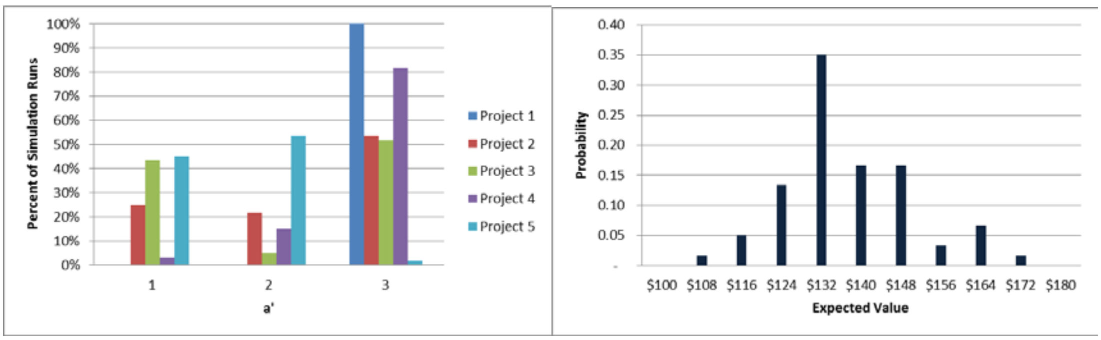

Fig. 2. (a) Initial year optimal decision; (b) Expected value over planning horizon (values in thousands)

4. Conclusions

The paper contributed a real options framework to plan a portfolio of projects to realize the target enterprise architecture. In our approach, we consider the flexibility available in the projects and systems to realize capabilities that are defined in the capability view of DoDAF. One benefit of the approach is to force decision makers to consider a phased commitment approach to deploying projects to deliver needed capabilities. The model is able to simultaneously consider multiple projects and their interactions in determining the optimal portfolio of projects to realize enterprise transformation. The case study illustrates the main outline of the enterprise transformation model that maps capabilities to systems and projects that are then input to a real options switching model that is solved via Monte Carlo simulation to generate optimal project investment decisions. The output is the portfolio of projects to invest in for each year. In practice, the model would be re-run as time progresses and uncertainty is resolved because depending on how the cash flows evolve, different decisions may be better than the initial plan.

Even with Monte Carlo simulation, we still need to consider computational issues. For the small illustrative problem, only 100 simulations were performed, yet it took almost five hours of computation time. In larger problems, such as faced by the Department of Defense, there are many more capabilities and projects that would need to be considered. One limitation of the method is the integration of systems will lead to emergent properties that are not covered in the approach. Finally, since some of the input parameters must be estimated, we need to perform analysis to see how sensitive the decision results are to the input and any errors in the input estimation. Future work will consider these properties.

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