Capabilities-Based Engineering Analysis (CBEA)

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Mike Webb
The MITRE Corporation
mwebb@mitre.org

Abstract

This paper describes capabilities-based engineering analysis (CBEA) as a new analytical approach to support enterprise systems engineering (ESE). CBEA provides a framework for capabilities-based planning, programming, and acquisition analysis in a systemic approach to the purposeful evolution of a complex enterprise. This paper outlines the basic approach, guiding principles, and challenges of CBEA for researchers and practitioners of ESE.

1. Introduction

The increasingly complex, dynamic, and uncertain nature of today's world has led many enterprises to design and manage their organizations as systems of capabilities and outcomes, as opposed to collections of processes and reporting relationships [Haeckel 1999]. By organizing assets as systems of capability modules, an enterprise can engage challenges and opportunities more dynamically, and at the most fundamental level, such an organization can be managed as a purposeful complex adaptive system [Cohen & Axelrod 1999].

Capabilities-based engineering analysis (CBEA) is an engineering approach that supports such an enterprise strategy by focusing on the development and evolution of capabilities, rather than specific programs or functions. This paper introduces the basic principles and key analytical activities by which CBEA addresses the complex problem and solution spaces of enterprise systems engineering (ESE). The prime motivation for CBEA is to enable an enterprise to develop and evolve its critical capabilities in a highly complex and dynamic environment to bring superior value to its customers.

2. Capabilities View of the Enterprise

Economic theory has increasingly focused on the concept of *capabilities* as the defining characteristic of an enterprise, and this view has propagated through the fields of business and management. Indeed, in its firm-oriented incarnation, evolutionary economics [Nelson & Winter 1982] is often referred to as *the capabilities view* [Foss 1993]. In this view, an enterprise is conceptualized and distinguished in terms of its unique capabilities, and these capabilities are considered to be the most potent source of competitive advantage, growth, and success of an enterprise [Collis 1994].

2.1. The Complex Context

Central to the capability view is a primal focus on deploying enterprise resources to achieve end-user effects or outcomes [Haeckel 1999]. However, the focus on purposeful effects is typically complicated by the complexity of the enterprise and the environment in which it operates. Figure 1 illustrates a high-level view of an enterprise and the issues attendant to its complex context.

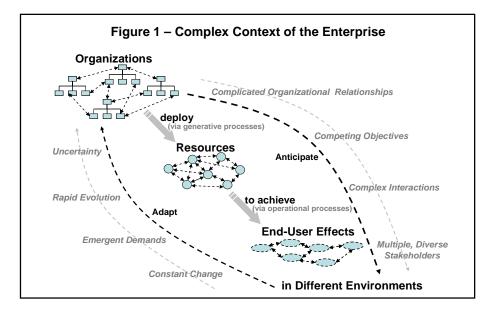


Figure. 1. The Capabilities-Based View of the Enterprise

The complex environmental context shapes the efficacy of the enterprise. For example, in evolutionary economic theory [Nelson and Winter 1982], organizational capabilities and decision rules evolve over time through deliberate problem-solving and random events. An economic analogue of natural selection operates as the market determines which firms are and are not viable in the real-world difficulties of complexity, uncertainty, and bounded rationality. Interestingly, the authors conclude that attempts at long-range optimization and control of technological advances will lead not to efficiency but to inefficiency.

This capabilities perspective is not limited to commercial enterprises; the United States Department of Defense (DoD) has adopted such a view to operate in today's complex, uncertain world. The 2001 Quadrennial Defense Review [DoD 2001] promulgated a capabilities-based approach to planning that was reaffirmed and detailed in the recent Joint Defense Capabilities Study [Aldridge 2004]. Capabilities-based planning has been defined as "...planning, under uncertainty, to provide capabilities suitable for a wide range of modern-day challenges and circumstances, while working within an economic framework" [Davis 2002].

2.2. The Focus of Enterprise Modernization

Researchers emphasize the need for an enterprise to invest in capabilities rather than functions or business units [Stalk, Evans & Schulman 1992]. Chandler [1990] views the integration, coordination, and maintenance of organizational capabilities to be as difficult as their creation, as changing technologies and markets constantly pressure capabilities toward obsolescence. The survival and growth of the enterprise depends on a continuing modernization of organizational capabilities.

As the pace of change continues to increase and the nature of that change becomes increasingly discontinuous, the concept of *dynamic capabilities* becomes a key concern of the enterprise. *Dynamic capabilities* are typically viewed as the ability to integrate, build, and reconfigure competencies to address rapidly-changing environments [Adner & Helfat 2003; Eisenhardt 2000; Teece et. al. 1997; Winter 2003]. CBEA is intended to serve as an adaptable approach to achieving dynamic capabilities.

3. CBEA -- Embodying Complex System Strategies

The complex systems paradigm has strongly influenced modern enterprise management theory, and numerous researchers have studied the implications of complexity for enterprise strategies [e.g. Beinhocker 1999; Brown & Eisenhardt 1998; Cohen & Axelrod 1999; Connor 1998; Haeckel 1999; Kelly & Allison 1999; MacIntosh & MacLean 1999; Sanders 1998]. In the context of capabilities analysis, complexity results from the interconnectedness of capabilities, the social relationships within the enterprise [Barney 1991] and from co-specialized assets, that is, assets which must be used in conjunction with one another [Teece 1986]. To address these issues, CBEA is founded on a few key strategies from complex systems theory.

3.1. Modularity

Inspired by "The Architecture of Complexity" [Simon 1962], many researchers advocate the adoption of modularity as a design principle to manage complexity [Baldwin & Clark 2000; Sanchez & Mahoney 1996; Schilling 2000]. The adoption of modular design principles for all aspects of the enterprise -- organization, resources, processes, and effects – entails the creation of semi-autonomous modules with stable and visible rules for communication and interaction. As long as the integrity of intermodule interaction is preserved, module designers are free to engage in local (e.g. within a module) adaptation or innovation.

4 Capabilities-Based Engineering Analysis (CBEA)

Partitioning the enterprise into capability categories, with attendant capability portfolios focused on critical end-user outcomes, is a core strategy of CBEA to manage complexity. However, as noted above, many interactions and complications are likely to remain to some degree across the enterprise. For example, while two systems may be weakly coupled structurally, they may be highly coupled functionally. Schaefer concludes that, "it would seem unlikely that a firm could ever hope to uncover an optimal modular design partition…" [Schaefer 1999, 325].

3.2. Exploratory Modeling & Analysis

Enterprise planning problems are typically characterized by enormous uncertainties that should be central considerations in the design and evaluation of alternative courses of action. A key approach to addressing pervasive uncertainty is *exploratory modeling & analysis* [Bankes 1993; Davis and Hillestad 2001; Lempert, Schlesinger & Bankes 1996]. The objective of exploratory analysis is to understand the implications of highly uncertain problem and solution spaces to inform strategy and design choices. In particular, exploratory analysis is intended to identify strategies that are flexible, adaptive, and robust.

CBEA uses exploratory modeling and analysis to examine enterprise capability issues in the broadest possible context of scenarios, conditions, and assumptions, readily complementing the technique of planning with multiple scenarios [Beinhocker 1999; Courtney 1997; Epstein 1998; Schoemaker 1997]. Relevant models and analysis methodologies should be able to reflect hierarchical decomposition through multiple levels of resolution and from alternative perspectives representing different aspects of an enterprise. Ideally, the analytical agenda should be able to examine the relative fitness of enterprises response to a great variety of possible futures.

3.3. Adaptive Evolutionary Planning

The complex dynamics of enterprise relationships suggest that enterprise evolution depends critically on factors other than global intention and design. Complex systems have the internal capacity to change in unpredictable ways that cannot be described by optimization planning approaches. Researchers point to the limits of predictability and conclude that reliance on a single evolutionary strategy is inappropriate [Beinhocker 1999; Pascale 1999]. Instead, the goal should be to develop a collection of strategies to facilitate ready adaptation to future changes.

As an extension of exploratory modeling and analysis, CBEA considers a broad set of risk factors (e.g. cost, schedule, performance, technologies) to envision alternative evolutionary paths. This implies planning for multiple options and adapting strategies as scenarios unfold. Preparing for multiple contingencies is a key element of an adaptive planning process. Haeckel [1999] emphasizes that creating an enterprise culture of adapting and responding is paramount to survival and success.

4. CBEA – Shaping the Evolution of Capabilities

CBEA is founded on the premise that an enterprise and its capabilities must be viewed as complex adaptive systems. This perspective fosters a change in focus from specific

programs or functions to a capability-centric design that facilitates horizontal integration of a distributed, mission-oriented enterprise. CBEA supports this perspective by analyzing enterprise capabilities, linking capabilities to portfolios of processes and resources, and identifying reconfigurations for effective adaptation.

The analytical approach is based on iterative analysis and design focusing on *structure*, *behavior*, and *effects*. *Structure* includes all system inputs and their relationships (e.g. policy, organization, training, materiel, leadership, personnel, and facilities) [Gharajedaghi 1999]. *Behavior* entails the action and performance required to produce outcomes, and *effects* are the resulting operational outcomes. These three dimensions, their interdependencies, and their interactions with the environment provide the foundation for a holistic enterprise analysis methodology.

4.1. Analytical Principles

Based on the foregoing context and motivations, CBEA is founded on a set of key set of analytical principles:

- Focus on outcomes (desired operational effects) of the enterprise end-user, vice inputs such as particular programs, platforms, or functions.
- 2) Frame a *portfolio perspective* as a means of partitioning the problem and solution spaces in terms of capabilities (*capability partitions or modules*).
- 3) Approach issues holistically, examining all aspects of structure, behavior, and effects; consider a full range of alternative solutions to provide a capability.
- 4) Examine the complex networks of interdependencies. Such interdependencies exist across all the fundamental dimensions of analysis (structure, behavior, and effects), in multiple aspects, at different levels of hierarchical description.
- 5) Explicitly bound profound uncertainties attendant to complex adaptive system problems; all assessments must be accompanied by rigorous risk analysis.
- 6) Pursue an adaptive evolutionary approach to planning to position the enterprise to effectively respond to changes as they occur.
- 7) Assess and balance the evolution of capabilities within resource constraints for a wide range of diverse and stressing operational circumstances.

4.2. Analytical Activities

The scope and complexity of the capabilities-based enterprise perspective requires a disciplined and robust analytical construct capable of assessing and managing risk across very diverse and uncertain problem sets, with consideration and competition of a broad range of solution approaches constrained by cost and resource constraints. The need for engineering analysis pervades this perspective, and CBEA addresses this need.

Figure 2 identifies the basic modules and general flow of CBEA. The modularized schema is not a standardized process, but a collection of interrelated analytical activities that can be assembled as needed to support capabilities-based planning. All the

modules interrelate, but there are three major phases: 1) purposeful formulation; 2) exploratory analysis, and 3) evolutionary planning.

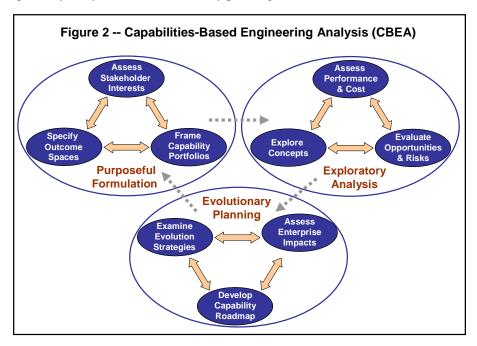


Figure. 2. Capabilities-Based Engineering Analysis Activities

Purposeful formulation establishes the framework for analysis in a participative process that engages stakeholders as purposeful systems [Ackoff & Emery 1972]. Based on a thorough review of stakeholder needs and objectives, the analytical process specifies the relevant outcome spaces, that is, the operational goals, contexts, and conditions for which solutions must be designed. A significant part of the CBEA approach is to stimulate analysts to consider a wide set of possible scenarios and conditions against which solution options are evaluated by outcome-based metrics. Based upon the outcome space descriptions, the baseline capability portfolio is bounded and described. A capability portfolio includes all the structural elements that must cooperate to provide the desired operational outcomes in a capability area.

The exploratory analysis activities of CBEA assess the performance and cost of portfolio options over the broad range of formulated contexts, while generating new concepts for possible improvement. The focus of performance evaluation is an assessment of capability risks and opportunities, emphasizing the identification of critical capability drivers, capability gaps, and possible options for significant improvement. The focus on capabilities, vice existing solutions, facilitates proposals for new ways and means to accomplish missions, potentially fostering new transformational capabilities. CBEA emphasizes competition among creative alternative solution concepts, with cost considerations serving as critical constraints in defining feasible solutions (e.g. cost as an independent variable).

CBEA evolutionary planning activities focus on developing flexible, robust, and adaptive approaches to the development and fielding of solutions within the context of capability portfolios and the broader enterprise. Central to this effort is the examination and integration of alternative evolution strategies aimed at synchronizing component structures and behaviors under different possible contingencies; different time-phased cost and performance profiles are developed for different evolution paths. Beyond a single capability portfolio, plans must be assessed for their impacts (e.g. technical, functional, and resource) on other capability portfolios and the broader enterprise. Such planning assessments are typically integrated in a capability roadmap that summarizes the results of the analysis and decisions.

5. Summary & Conclusions

CBEA is a key element of enterprise systems engineering; it is the analytical framework that supports capabilities-based planning, programming, and acquisition in a systemic approach to the purposeful evolution of the enterprise. The purpose of CBEA is to help enterprise decision-makers adjudicate risks through their policy and resource decisions in a highly uncertain, dynamic, and complex environment. In this context, a focus on capabilities provides the guiding principles and raison d'être of the enterprise.

This work outlines the key principles and processes of CBEA that can be adapted to provide the needed engineering analysis for a broad set of enterprise management issues. CBEA principles and processes, derived from basic strategies to deal with complexity, are relatively new and will continue to evolve. The need to focus on enduser capabilities in a complex, dynamic and uncertain world will continue to motivate the development of CBEA.

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