

An Activity Framework for COTS-Based Systems

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As use of commercial technology and products in systems becomes increasingly popular, particularly for government organizations, a new understanding of the dynamic principles of system creation is needed. However, there is little information on how using commercial off-the-shelf (COTS) products affects existing system development practices or what new processes are needed to be successful with COTS products. As part of the COTS-Based Systems Initiative at Carnegie Mellon University's Software Engineering Institute (SEI), we are studying this new software development process and have started to articulate some of the activities and practices that can be followed for development and lifetime support of COTS-based systems.

Many government and industry programs are discovering difficulties that can accrue in creating a COTS-based system [1, 2, 3]. Some are starting to describe new processes and procedures [4, 5]. But none of this work brings together a description of all of the activities—engineering, business, contractual, and management—that are new or changed as a result of using COTS products and technology.

The basis of our work is more than 30 medium and large projects, ranging from business information management systems to embedded weapon and military command and control systems. We have captured information about the practices that did and did not work. This information has been analyzed to understand and characterize the common points of success and failure. This resulted in identifying the process changes required to address these real-life lessons and the articulation of a framework for organizing the new and changed process elements.

In this article, we will summarize the essential factors that distinguish COTS-based systems (CBS) and describe a preliminary framework that captures new and changed activities necessary for a CBS approach. It is drawn from the collective experience of the members of the CBS Initiative at the SEI and studies undertaken in the context of working with individual organizations on their systems [6], [7]. In many instances the strawman framework describes parts of approaches that have been used by organizations. To date no one organization has consciously pursued their work according to this set of ideas. The framework and its contents can be used by projects in several ways: to determine what practices are required for effective leverage of the COTS marketplace, to identify the difference between their existing practices and those required, or to determine a suitable migration path.

CBS Process Drivers

Many software practitioners today are unfamiliar with CBS development, potentially involving a dozen or more COTS products¹ and custom or legacy components that provide system functionality. A philosophy and process that is different from that familiar to custom developers is needed for COTS-based systems. New process drivers flow from the definition of a “COTS product” and from the consequences of assembling things from purchased parts:

- CBS development is an act of composition.
- CBS development is shaped by realities of the COTS marketplace.
- CBS development occurs through the simultaneous definition and tradeoffs of the COTS marketplace, your architecture, and your system context.²

CBS Development as Act of Composition

The first driver holds that the development of a custom system is essentially an act of creation, whereas the development of a COTS-based system is ultimately an act of composition and reconciliation. Custom development starts with the system requirements and creates a system that meets them—we are producers. However, CBS development starts with a general set of requirements and then

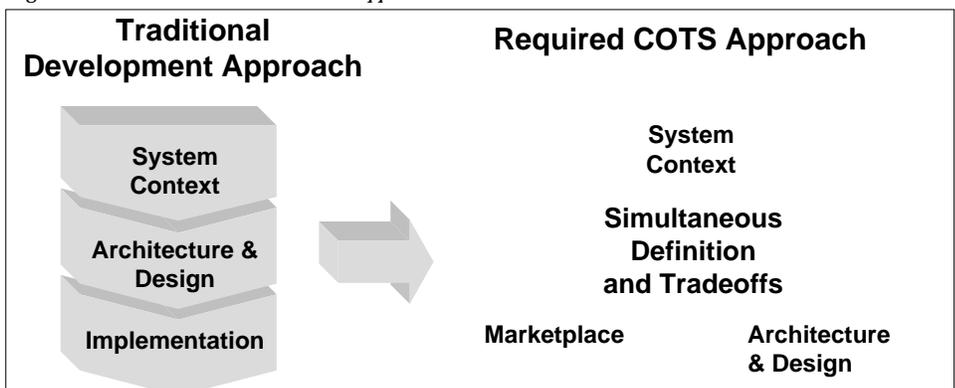
explores the offerings of the marketplace to see how closely they match the needs—we are consumers who must integrate the products we buy into a system that meets the need. The nature, timing, and order of activities done and the processes used differ accordingly.

CBS Development Shaped by Realities of COTS Marketplace

Eight inherent marketplace characteristics help determine the nature and evolution of a COTS-based system endeavor:

- There is frequent, continuous change in COTS products and the marketplace.
- The marketplace, noth the needs of any particular system, drives COTS products.
- Products have built-in assumptions about how they will be used; these might not match the system users' processes, resulting in clashes.
- Licensing and data rights will affect cost, architecture, and data processes.
- Projects have limited control over a COTS product's release frequency or content.
- Projects have limited visibility into COTS products' source code and behavior.
- Products are built on architectural assumptions that can vary across system components and could conflict with an evolving system architecture.
- COTS products have interdependencies.

Figure 1. *Traditional vs. COTS-Based Approach*



CBS Development Through Simultaneous Definition/Tradeoffs

The last driver of CBS processes is really a consequence of the previous two: there is a fundamental change required in the approach to system development for COTS-based systems, as pictured in Figure 1. On the left is a traditional custom-development approach in which requirements (referred to as system context) are identified, then an architecture defined, and finally (custom) implementation is undertaken.

But if this is applied to CBS, it is unlikely that the marketplace will yield any products that fit the *a priori* requirements and architecture. Instead, with CBS it is necessary to consider system context, architecture, and the marketplace *simultaneously*, as pictured on the right of Figure 1. Any of the three may have impacts on the other two; none can proceed without knowledge and accommodation of the other two. Further, the activities that are performed for CBS systems are cyclic in nature; these tradeoffs will be repeated frequently throughout the lifetime of the system. This fundamental change not only necessitates changes in the engineering processes but also in the processes used to acquire and manage the construction of such systems.

CBS Activity Areas

To understand the process changes

generated by the use of COTS products, we identify activities that are either new for COTS-based systems or were present in custom development but change for CBS development. These activities are grouped into four major *activity areas* in Figure 2: Engineering, Business, Program-wide, and Contract. Engineering and Business activity areas are straightforward. The Contract activity area covers issues involved in contracting with vendors and integrators. The Programwide activity area accounts for activities that are not contained in one area but span multiple areas.

Within each of these activity areas, the new and changed activities are categorized into a number of *activity sets*, represented as blocks in Figure 2. Each set of activities operates continuously. There is no implied sequence within an activity area. Rather, the activity sets represent categories of related activities. For each activity set, we have identified its scope, the activities, and usage guidance or tips to consider in defining and applying the activities.

Our goal is to emphasize the differences from traditional custom development processes. Sometimes the differences are not in *what* is done but rather *how* or *when* or with what *marketplace considerations* the activity is done. For example, the activities in the CBS Risk Management activity set are the same activities used in any form of risk man-

agement. The difference derives from the nature of COTS risks associated with the use of COTS products that have not been encountered before and the diversity of the mitigations that are required.

The activity areas and their activity sets are a preliminary notional model that would be used to guide the detailed planning of a specific program. Depending on the particular needs of a program, some activity sets would have greater emphasis than others. The identified activity sets apply not only to new programs but also to existing programs.

In the sections that follow, each activity area is summarized indicating some implications of the CBS process drivers, some of the interrelationships among the activity sets, and a tabular illustration of an activity set to indicate the type of information we have gathered. A more complete treatment of each activity area and its associated activity sets is provided in [8].

Engineering Activity Area

The Engineering Activity Area, as shown in Figure 2, is associated with the technical conceptualization, construction, and maintenance of a system. To a large extent these activity sets operationalize the CBS approach indicated on the right side of Figure 1. Activities in one set are done concurrently with and with mutual cognizance of other activity sets.

System Context Activity Set (an extract is shown in Table 1). Mismatches between end-users' processes and the processes embodied in COTS products will occur, and these differences will constrain the system context and the program's ability to leverage the marketplace. Late discovery of these mismatches has been the foremost COTS issue for many projects we studied. Combined with other features of the CBS process drivers, these mismatches demand early and continual involvement of the program's stakeholders across all engineering activity sets. Their help is needed in deciding the potential tradeoffs between requirements and available COTS products and technologies; things move too fast to recover if their input is sought too late.

Marketplace Activity Set. COTS-based systems are by their nature highly evolutionary. This derives in part from the usual changes in end-user needs. But new CBS process drivers show that the

Figure 2. COTS-Based Systems Activity Areas



<p>System Context: Encompasses considerations that define, prioritize, and constrain the CBS to be fielded, such as functional/nonfunctional requirements, end-user operations, business drivers, operational environment, and constraints such as schedule and budget.</p>	
<p>Activities</p> <ul style="list-style-type: none"> • Determine and prioritize the negotiable/non-negotiable elements of the system context. • Understand the essential elements of the business processes and identify process/product mismatch before committing to the marketplace. • Re-engineer business processes in light of knowledge of available products. • Negotiate system context changes as part of COTS-based tradeoffs. • Dynamically reflect results of COTS-based tradeoffs in the system context. • Re-examine COTS products for opportunities to optimize user processes. 	<p>Tips</p> <ul style="list-style-type: none"> • Requirements analysis is still a necessary activity, although a new process is required to deal with simultaneous tradeoffs. • Leverage prototypes to gain sufficient product insight to understand the extent of match with the end-user processes. • End users tend to consider current processes and preferences to be non-negotiable. • Engage all appropriate stakeholders early and often.

Table 1. Extract from System Context Activity Set

marketplace creates a new source of evolutionary demands, based both on the natural ebb and flow of products and technologies and on end-user discovery of new capabilities that have emerged in the marketplace.

Architecture Activity Set. The evolutionary nature of the marketplace has a particularly strong impact on the system architecture and design, as both must now be devised to withstand years, if not decades, of change. An architecture that allows a system to evolve efficiently is a strategic asset for CBS—it is the only thing the project owns.

Construction Activity Set. COTS product modification is often a temptation. Avoid it; if it cannot be avoided, successful projects go into it with a clear understanding of what it will mean in the future. “Modified COTS” is an oxymoron; once you have modified a COTS product for a specific use or system, it is no longer COTS. System lifetime costs of COTS product tailoring or modification must be taken into account as part of architectural and product selection decision-making.

Configuration Management Activity Set. Configuration management is still critical, but there are additional demands. Product versions and product dependencies on specific versions of other products must be tracked. License information and management (in the Contract activity area) may need to be accommodated as well.

Deployment and Sustainment Activity Set. The traditional separation of development and sustainment blur and become indistinguishable. Sustainment events, such as product upgrades, will occur before initial delivery of the system, and construction activities such as product selection, test, and integration will be necessary during sustainment. This impacts many other activities, such as budgeting, staffing, and contracting, and holds true from the purchase of the first product until retirement of the system.

Evaluation Activity Set. Evaluation of products and technologies begins from the moment the initial idea for a system is conceived, permeating and underlying all the other activities continuously throughout the CBS lifetime. This suggests dedicated evaluation resources (people, software, hardware, and facilities) as the useful half-life of market information is very short—about six months—and product information may not be valid for significantly longer periods of time.

<p>COTS Business Case: Provides the basis for “make vs. buy” decisions for an entire system or an individual component. Covers the information gathering and analyses necessary to reach a recommendation regarding which of several alternative COTS or custom solutions to choose. Uses many of the other engineering and business activity sets.</p>	
<p>Activities</p>	
<ul style="list-style-type: none"> • Determine CBS success factors. • Conduct preliminary study of feasibility of a solution using COTS products. • Identify key COTS-related assumptions. • Articulate alternatives to be analyzed. • Formulate CBS strategic plans. • Analyze financial implications (costs, CBS risks, costs for risk mitigation). • Analyze (COTS and non-COTS) alternatives and determine recommendation(s). • Revisit the business case periodically and at key reassessment events. 	
<p>Tips</p>	
<ul style="list-style-type: none"> • Information gathering is key. Beware of the very short half-life of the information due to marketplace volatility. Beware that comparisons are not usually of the “apples to apples” variety. 	

Table 2. Extract from COTS Business Case Activity Set

Business Activity Area

The Business Activity Area (refer to Figure 2) is associated with developing the business case and cost estimates, and managing vendor and other supplier relationships. COTS product and technology decisions are not just engineering decisions, they are also business decisions. Many activities in the business activity area require information from the engineering activity area and vice versa. For example, to create a COTS business case requires detailed COTS product information derived from the Marketplace and Evaluation activity sets plus architectural and design prototypes from the Architecture activity set.

COTS Business Case Activity Set (an extract is shown in Table 2). Making a COTS product purchasing decision in most cases is more than buying a commodity. A program’s potential success may now be tied to a critical component from the vendor, requiring an effective long-term business relationship. The purpose of the business case is to analyze the alternatives to find the one with the best return on investment, total cost of ownership, and risk profile that best fits the requirements across the life of the system. Business decisions made regarding COTS products and technologies must incorporate the total cost of ownership across the system life, not just initial purchase costs. A key part of constructing the COTS business case is gathering information from such sources as market research and trend analysis, gap analysis between the product and your requirements, investigations of vendor health and practices, and detailed product usage through prototypes, demonstrations, and pilots.

COTS Cost Estimation Activity Set. The CBS process drivers are felt as strongly in the business activity area as in engineering. CBS cost estimation must account for all the differences for CBS implied by the CBS process drivers. In addition to many traditional costs, a CBS may incur costs for reacting to new product releases and marketplace changes (including “end-of-life” events), technology refresh, continuous evaluation, marketplace and technology watches, licensing, (re)integration, etc. Development of new publicly available COTS cost estimation techniques and models is in its infancy.

Vendor Relationships Activity Set. A vendor relationship is the means of partnering with a vendor that is important to your

system. The relationship relies on a cooperative exchange that explores current and future vendor and government plans. Such relationships provide insight into product releases, and represents a means for the government to influence vendor plans or directions. The type and depth of vendor relationship is dependent on the importance of the COTS product to the system and the importance of the program as a customer of the vendor.

Intergovernmental Supplier Relationships Activity Set.

For DoD programs, another DoD organization may be the supplier of a nondevelopmental item that is incorporated into your system. The other DoD organization is not a vendor but is a supplier who exhibits both similarities as well as differences from how a commercial vendor would operate. A program needs to cultivate and nurture a relationship with these suppliers

Contract Activity Area

The Contract Activity Area, indicated in Figure 2, is associated with the contractual aspects of creating and monitoring relationships with integration contractors and vendors. The first three activity sets focus on the contract relationship with an integration contractor. They emphasize the aspects that are different for a CBS contract, so they are not a complete guide to the contract effort for a CBS. The license negotiation activity set covers the contractual relationship with vendors.

Contract Requirements Activity Set. Contract requirements define the scope of the contract effort for CBS integration. They are developed with stakeholders, including potential bidders and suppliers. Contract requirements need to be flexible, traceable and verifiable, and address the system service lifetime. Contract requirements should accommodate CBS issues such as (but not limited to) technology refresh, version upgrade plans, market and technology watch groups, evolvable architecture, and supplier support.

Solicitation Activity Set. Look for CBS contractors who show successful previous CBS experience and knowledge of the COTS marketplace relevant to your domain. Consider carefully that their engineering and management practices provided in their proposals address the CBS issues and the risks specific to your program. Realistic demonstrations should be a key part of the contractor selection process in many situations.

Contract Tracking and Oversight Activity Set. Execution of activities for this activity set requires government skill and experience in such areas as COTS cost estimation, oversight of

Table 3. *Extract from License Negotiation Activity Set*

License Negotiation: Looks at what the vendor offers with respect to terms, conditions, and costs for a given product for use in an organization over a particular period of time. Based on the situation and needs of the organization, negotiates the license(s) that best suits both parties.	
Activities	Tips
<ul style="list-style-type: none"> Investigate licensing alternatives and costs; capitalize on enterprise licensing opportunities. Incorporate nonstandard provisions, such as vendor commitment to inclusion of modifications, integration support, notification of product splits, and license transfer. Negotiate licenses. 	<ul style="list-style-type: none"> License agreements may be used to describe the relationship with the vendor, incorporate nonstandard provisions such as vendor commitment, inclusion of modifications into the next commercial product release, and the kind and degree of integration support the vendor will provide.

contractor's iterative development, relevant marketplace trends, evolving the system architecture, and product upgrades and technology refresh issues.

License Negotiation Activity Set (partial extract shown in Table 3). License agreements lay the foundation for and embody the program's vendor relationships. They must withstand many changes to a vendor's product and must be carefully considered. In particular, the program must be sensitive to their impact on program costs and potentially on the system architecture.

Programwide Activity Area

The Programwide Activity Area (shown in Figure 2) covers the activities that span the Engineering, Business, and Contract Activity Areas in order to develop and sustain a CBS.

CBS Strategy Activity Set (extract shown in Table 4). The CBS strategy sets the stage for how a project will conduct all other activities. For example, the CBS strategy governs to what depth a COTS business case will be done, what investment will be made in vendor relationships, and what development approach will best support a CBS approach. Due to the continual changes in the COTS marketplace, a program will need to re-evaluate its CBS strategy periodically and adjust its plans and actions accordingly.

CBS Risk Management Activity Set. The goal of risk management for CBS is to identify COTS risks as early as possible, adjust the strategies and plans to manage those risks, and develop and implement a COTS risk management process as an integral part of an organization's overall CBS approach. Given marketplace volatility, COTS risks are likely to change more rapidly than the typical risks associated with custom systems. Examples of common COTS risks include a key vendor going out of business or an engineer's inability to integrate two selected products.

CBS Tradeoffs Activity Set. Engineering has always been an exercise in tradeoffs. With CBS, new tradeoff considerations arise, such as products that do not meet requirements, effects of licenses on design decisions, a vendor's or supplier's market share, architectural mismatch among components, long-term viability of a technology, product, or vendor, and the (mis)match of COTS product processes and existing end-user processes. Compounding the tradeoff issues is a program's lack

Table 4. *Extract from CBS Strategy Activity Set*

CBS Strategy: Seeks to derive an approach to COTS-based system development that will meet CBS objectives within program constraints over the life of the system. Provides for formulating, conducting and documenting planning activities for a CBS, providing one aspect of an overall system strategy. Factors in the realities about the COTS marketplace and the challenges that result into the system planning.	
Activities	Tips
<ul style="list-style-type: none"> Identify CBS goals, constraints, and assumptions. Identify COTS-related risks. Identify relevant market segments. Identify alternative COTS-based solutions. Reassess CBS strategy as necessary. Assess/evaluate/tradeoff alternative COTS-based solutions. Recommend an overall CBS strategy. Create a corresponding CBS plan, including contingency plans. Reassess and revise CBS strategy as necessary. 	<ul style="list-style-type: none"> Because of the presence of COTS products, the acquisition strategy/plan must be flexible enough to respond to changing circumstances. This requires, among other things, an understanding of how unprecedented your system is with respect to what the marketplace provides and with respect to what combinations have been successfully fielded for your application area in general and by your contractor.

of control over many of these sources of contention and an inability to compensate by modifying COTS products.

Cultural Transition Activity Set. COTS-based systems represent a change for everyone in an organization, not just technical personnel. New roles and skills are required. Failing to pay attention to the cultural transition issues could result in a potentially insurmountable barrier to CBS success. The more a program already uses sound system engineering practices, the easier it will be to transition to a CBS approach.

Information Sharing Activity Set. Information sharing can help save others from repeating known mistakes. When the pace of change accelerates, as with COTS products and technologies, flexibility becomes a business imperative. A program does not have the time to dig itself out of problems that could be avoided.

Future Directions

These results are preliminary. They require a great deal of application to validate and tune. We plan to use applicable activity sets with our customers, and we invite readers who choose to work with some or all of the activity sets, as described more fully in [8], to share their results with us. We expect to apply those results to evolve this preliminary framework. ♦

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Notes

1. A COTS product is a product that is sold, leased, or licensed to the general public; offered by a vendor trying to profit from it; supported and evolved by the vendor, who retains the intellectual property rights; available in multiple, identical copies; and used without modification of the internals.
2. The term *system context* is used to ensure inclusion of requirements in the context of their end-user processes and other constraints such as cost and schedule—not just functional requirements.

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The Guidelines for Successful Acquisition and Management of Software Intensive Systems (GSAM) is available free on the CD-ROM distributed by the Software Technology Conference 2000 only to those people who attended the conference. Others may purchase the CD for \$50 from Utah State University. For a copy, contact Vivian Johnson at (435)797-0424 or vivian@ext.usu.edu.

The GSAM is also available on the Software Technology Support Center's web site at www.stsc.hill.af.mil, and will be included in a future release of the Defense Acquisition Deskbook. No hard copies will be available.