

Composable Process Elements for Developing COTS-Based Applications

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Abstract

Data collected from five years of developing e-service applications at USC-CSE reveals that an increasing fraction have been commercial-off-the-shelf (COTS)-Based Application (CBA) projects: from 28% in 1997 to 60% in 2001. Data from both small and large CBA projects show that CBA effort is primarily distributed among the three activities of COTS assessment, COTS tailoring, and glue code development and integration, with wide variations in their distribution across projects. We have developed a set of data-motivated composable process elements, in terms of these three activities, for developing CBA's as well an overall decision framework for applying the process elements. We present data regarding the movement towards CBA's and effort distribution among them; we then proceed to describe the decision framework and to present a real-world example showing how it operates within the WinWin Spiral process model generator to orchestrate, execute, and adapt the process elements to changing project circumstances.

1. Introduction

In his ICSE 2002 keynote address [3], Robert Balzer issued a challenge to the software engineering community to provide better methods for dealing with COTS-based software systems, and to present them at subsequent ICSE's. This paper provides a partial response to this challenge. It presents some data that we have found useful in understanding COTS-based application (CBA) trends and effort distributions. The COTS effort distributions and sequences also suggest a framework for the primary contributions of the paper: a set of composable process elements and a decision framework for using them in the development of CBA's.

Traditional sequential requirements-design-code-test (waterfall) processes do not work for CBA's [11], simply because the decision to use a COTS product constitutes acceptance of many, if not most, of the requirements that led to the product, and to its design and implementation. In fact, it is most often the case that a COTS product's capabilities will drive the "required" feature set for the new product rather than the other way around, though the choice of COTS products to be used should be driven by the new project's initial set of "most significant requirements." Additionally, the volatility of COTS products [9] introduces a great deal of recursion and concurrency into CBA processes.

Some recent CBA process models have partially addressed these issues by adding CBA extensions to a sequential process framework [8]. These work in some situations, but not in others where the requirements, architecture, and COTS choices evolve concurrently; the example in Section 4 illustrates this point.

Other process frameworks such as the spiral model [5] and the SEI Evolutionary Process for Integrating COTS-Based Systems (EPIC) process [2] provide suitably flexible and concurrent frameworks for CBA processes. However, they have not, to date, provided a specific decision framework for navigating through the option space in developing CBA's. They identify key activities (evaluate alternatives; identify and resolve risks; accumulate specific kinds of knowledge; increase stakeholder buy-in; make incremental decisions that shrink the trade space), but leave their sequencing to the individual CBA developer.

The decision framework presented here is based on our experience in analyzing large CBA's in the course of gathering empirical data for the Constructive CBA cost model (COCOTS), a COTS counterpart to COCOMOII [1,6], and our experience developing and analyzing several dozen e-services CBA's for USC's Information Services Division and its Center for Scholarly Technology [4].

Section 2 provides relevant definitions and context. Section 3 presents the CBA process decision framework and composable process elements. Section 4 presents an update to the WinWin Spiral Model, and illustrates, via an actual example, how it, the CBA decision framework, and the composable CBA process elements were used to converge on the most appropriate composite CBA process for that example. Section 5 provides conclusions.

2. Definitions and Context

2.1 Definitions

We adopt the SEI COTS-Based System Initiative's definition [7] of a *COTS product*: 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;
- Used without source code modification.

We also follow the SEI in defining a *COTS-Based System* very generally as "any system, which includes one

or more COTS products.” This includes most current systems, including many which treat a COTS operating system and other utilities as a relatively stable platform on which to build applications. Such systems can be considered “COTS-based systems,” as most of their executing instructions come from COTS products, but COTS considerations do not affect the development process very much.

To provide a focus on the types of applications for which COTS considerations do affect the development process, we define a *COTS-Based Application* as a system for which at least 30% of the end-user functionality (in terms of functional elements: inputs, outputs, queries, external interfaces, internal files) is provided by COTS products, and at least 10 % of the development effort is devoted to COTS considerations. The numbers 30% and 10% are not sacred quantities, but approximate behavioral CBA boundaries observed in the application projects. There was a significant gap observed in COTS-related effort reporting. The projects observed either reported less than 2% or over 10% COTS-related effort, but never between 2-10%.

In our six years of iteratively defining, developing, gathering project data for, and calibrating COCOTS cost estimation model, we identified four primary sources of project effort due to CBA development considerations. These are defined in COCOTS as follows:

- COTS *Assessment* is the activity whereby COTS products are evaluated and selected as viable components for a user application.
- COTS *Tailoring* is the activity whereby COTS software products are configured for use in a specific context. This definition is similar to the SEI definition of “tailoring” [10].
- COTS *Glue Code* development and integration is the activity whereby code is designed, developed, and used to ensure that COTS products satisfactorily interoperate in support of the user application.

2.2 CBA Growth Trend

An increasing fraction of CBA projects have been observed in over five years’ USC-CSE e-services project data. As seen in figure 2.1, the CBA fraction has increased from 28% in 1997 to 60% in 2001.

Major considerations for adopting COTS products in these projects are: 1) the clients’ request, 2) the schedule constraint, 3) compliance with organization standards, and 4) the budget constraint. The primary reason for the growth in COTS content has, however, been the large increase in the number of COTS products providing application functions. In 1997, most of the teams were programming their own search engines and Web crawlers, for example; by 2001 these functions were being accomplished by COTS products.

Some of our USC-CSE affiliates have reported similar qualitative trends, but this is the first quantitative data they and we have seen on the rate of increase of CBA projects under any consistent definition and in any application sector (e-services applications probably have higher rates of increase than many other sectors). We have experienced many notable effects of this increase: for example, programming skills are necessary but not sufficient for developing CBA’s (see also 8,9,10,11)].

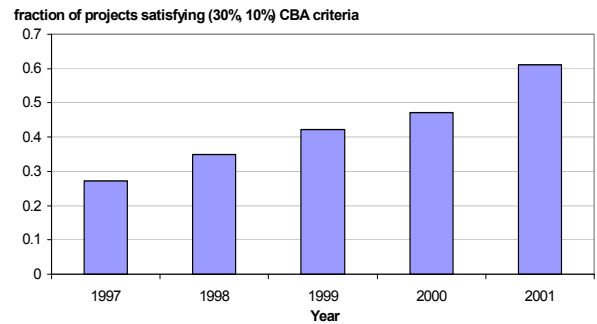


Figure 2.1 CBA Growth in Small E-Service Projects

2.3 CBA Activity Distribution

Based on 2000-2002 USC-CSE e-services data and 1996-2001 COCOTS calibration data, we observe a large variation of COTS-related (assessment, tailoring, and glue code) effort distributions. This is clearly illustrated in the e-services and COCOTS COTS effort distributions in Figures 2.3a and 2.3b respectively.

The industry projects in Figure 2.3b were a mix of

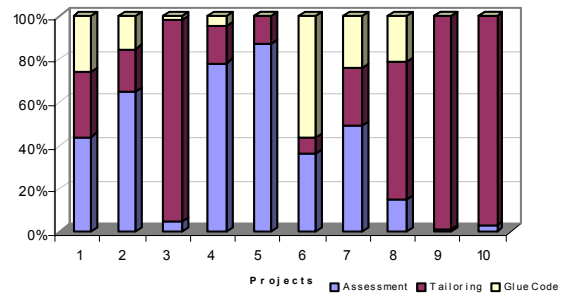


Figure 2.3a. CBA Effort Distribution of USC e-Service Projects

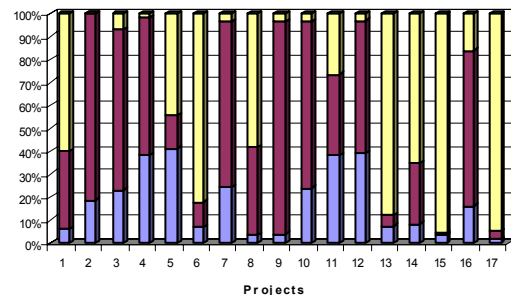


Figure 2.3b. CBAs Effort Distribution of COCOTS Calibration Data

small-to-large business management, engineering analysis, and command control applications. Assessment effort ranged from 1.25 to 147.5 person-months (PM). Tailoring effort ranged from 3 to 648 PM; glue code effort ranged from 1 to 1411 PM.

Some CBA approaches, including our initial approach to COCOTS, just focus on one CBA activity such as glue code or assessment. As shown in Figure 2.3a, some projects (projects 3, 8, 9, 10) are almost purely tailoring efforts, while other projects (projects 2, 4, 5) spent most of the time on COTS assessment. The industry projects in Figure 2.3b have similar attributes. We also note that all projects had some degree of assessment, and so we never have observed tailoring or glue code only efforts, or a mix of only these two. In addition, the assessment and glue code-only combination is very rare.

In previous work [12] these observations have led us to believe that there are typically three types of CBA projects. These are chiefly-assessment oriented; chiefly assessment and tailoring; or a significant mix of all three COTS-related activities. We found that different CBA types had significantly different project attributes (such as requirements flexibility), risk profiles, and project development characteristics.

Another notable fact found from looking at effort data that was collected on a weekly basis, is that assessment activities (A), tailoring activities (T), and glue code development (G) are not necessarily sequential. Table 1 shows a sampling of the A, T, G sequences for some of the e-services projects (we also denote custom development with the letter C). The sequences of activities are time ordered from left to right and activities undertaken in parallel are indicated by placing the activity letters within parentheses. We note that all sequences begin with assessment. We also note that the small cycle of ATG or A(TG) is very common and often repeating combination.

The different combinations of assessment, tailoring, and glue code activities resulted from insufficient earlier assessment (for example, project No. 6), COTS changes (Project No. 5, 7), or requirement changes (project No. 4). Such decision factors are not directly addressed by the current literature on CBS processes. Therefore, we have developed a CBA process decision framework and a set of composable process elements to address and accommodate these critical factors. This decision framework is consistent with our empirical data and the distribution and sequence observations discussed in this section.

3. CBA Process Decision

No.	Process Map
4	ATGC
5	ATA
6	A(TG)AG
7	A(TG)A(TG)

Table 1. CBA Effort Sequences

Framework and Process Elements

As evidenced in section 2.3, there are a wide variety of CBA effort distributions, and the particular effort distribution of a CBA significantly reflects its project risks and development characteristics. As such, applying a one-size-fits-all development process is likely to encounter difficulties in addressing the needs and risks of a given CBA.

As the fraction of CBA's has increased among our USC e-services projects, we have encountered increased conflict between CBA process needs and our UML-based MBASE process and documentation guidelines. This has led to a good deal of confusion, frustrating re-work, risky decisions, and a few less than satisfactory products.

A notable example of this re-work occurred within one of the authors' "USC Collaborative Services" project in which the developers scrapped (after much expended effort) their process-mandated UML based design models and substituted extensive and detailed assessments and comparisons of several COTS packages, each of which covered most or all of the desired capabilities.

In analyzing this problem, we found that the ways that the better projects handled their individual assessment, tailoring, and glue code activities exhibited considerable similarity at the process element level. We also found that these process elements fit into a recursive and reentrant decision framework accommodating concurrent CBA activities and frequent go-backs based on new and evolving OC&P's and COTS considerations. We now describe the CBA process decision framework and its respective assessment, tailoring, and glue code elements.

3.1. The CBA Process Decision Framework

Figure 3.1 presents the dominant decisions and activities within CBA development as abstracted from our observations and analysis of USC e-services and CSE-affiliate projects. This represents the overall CBA decision framework that composes the assessment, tailoring, glue code, and custom code development process elements within an overall development lifecycle.

Some explanation of Figure 3.1 is in order. The CBA process is undertaken by "walking" a path from "start" to "Non-CBA Activities" that connects (via arrows) activities as indicated by boxes and decisions that are indicated by ovals. Activities result in information that is passed on as input to either another activity or used to make a decision. Information follows the path that best describes the activity or decision output. Only one labeled path may be taken at any given time for any particular walk; however it is possible to perform multiple activities simultaneously (e.g. developing custom application code and glue code, multiple developers assessing or tailoring).

The small circles with letters A, T, G, C indicate the assessment, tailoring, glue code, and custom code development process elements respectively. With the

exception of the latter, each of these areas will be expanded and elaborated in the sections that follow. These areas can generate the development activity sequences indicated in Table 1 by noting the order that these process elements are visited. Each area may enter and exit in numerous ways both from within the area itself or by following the decision framework of Figure 3.1. In addition, this scheme was developed from and is consistent with the CBA activity distributions of Figures 2.3. In particular, only (and in fact all) “legal” distributions are possible (e.g. that all distributions have assessment effort is consistent with all paths in the framework initially passing through the assessment element (or area “A”). We now summarize the less obvious aspects of each process area.

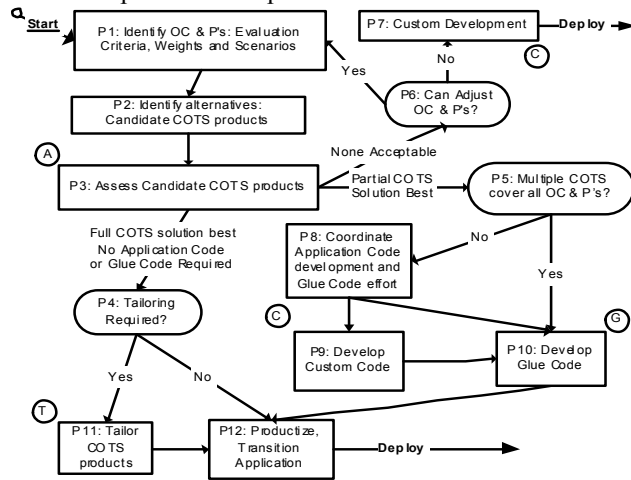


Figure 3.1. CBA Effort Decision Framework

P1: Identify OC&P's: Evaluation Criteria, Weights and Scenarios. This is the entrance to the CBA process where the initial evaluation attributes and desired operational outcomes for the application are established. Risk considerations, stakeholders’ priority changes, new COTS releases and other dynamic considerations may significantly alter the objectives, constraints, and priorities (OC&P's). In particular, if no suitable COTS packages are identified, the stakeholders may change the OC&P's and the process is started over with these new considerations.

P2: Identify alternatives: Candidate COTS products. This and activity P1 establish the entry conditions for an Assessment activity.

P5: Multiple COTS cover all OC & P's? If a combination of COTS products can satisfy all the OC&P's, they are integrated via glue-code. Otherwise, COTS packages are combined to cover as much of the

OC&P's as feasible and then custom code is developed to cover what remains.

P6: Can Adjust OC & P's?

When no acceptable COTS products can be identified, the OC&P's are re-examined for areas that may allow more options. Are there constraints and priorities that may be relaxed that have eliminated some products from consideration? How firm are the objectives and if adjusted slightly will it enable consideration of more products? Are there analogous areas in which to look for more products and alternatives?

P8: Coordinate Application Code development and Glue Code effort.

Custom developed components must eventually be integrated with the chosen COTS products. The interfaces will need to be developed so they are compatible with the COTS products and the particular glue code connectors used. This means that some glue code effort will need to be coordinated with the custom development.

3.2. Assessment Process Element

COTS assessment aims at helping to make buy-or-build choices and helping select the most satisfactory combination of COTS products from various candidates. Current approaches to COTS assessment processes identify key tasks and emphasize the concurrency and high coupling involved in the tasks [14,15]. But they leave open how COTS assessment fits with tailoring, glue code, and the overall process. Here we present a COTS assessment process that provides these linkages as shown in Figure 3.2:

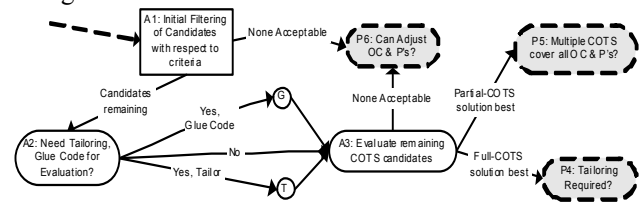


Figure 3.2. The Assessment Process Element

Entry Conditions for Assessment

The entry condition for assessment assumes that suitable COTS evaluation criterion, their corresponding weights, business scenarios, and COTS candidates are present (starting with the results of Fig. 3.1 decision elements P1 and P2).

Evaluation criteria and weights are established based on stakeholder-negotiated OC&P's for the system. Stakeholders also agree on the business scenarios to be used for the assessment. The assessment sub-model of COCOTS has collected an extensive list of attributes used in COTS evaluation [1,6].

A1: Initial Filtering. Initial assessment tries to quickly filter out the unacceptable COTS packages based on the evaluation criteria. The objective of this activity is to reduce the number of COTS candidates needing to be evaluated in detail. If no available COTS products pass this filtering, this assessment element ends up at the “none acceptable” exit.

A2: Tailoring or Glue Code Needed for Evaluation. The remaining COTS candidates from initial filtering will undergo more detailed assessment. To do so, some COTS products need to be tailored (e.g., to assess usability), and some need to be integrated by glue code development (e.g., to assess interoperability).

A3: Detailed Assessment. The focus of detailed assessment is to collect data/information about each COTS candidate against evaluation criteria from pre-designed business scenarios, analyze the data and make decision trade-offs. Some useful techniques are listed here:

1. Use a market watch activity to get the latest COTS information, and collect COTS information from its current users to gain first hand COTS experience from its current user group.
2. Assess vendor supportability to address life cycle issues such as system refresh and maintenance.
3. Develop, instrument, and evaluate prototypes, benchmarks, simulations, or analytic models to analyze key performance parameters and tradeoffs.

A screening matrix or analytic hierarchy process is a useful and common approach to analyze collected evaluation data. The evaluation criteria and COTS candidates work as the columns and rows of the matrix respectively. The final score for a particular COTS candidate is the weighted sum of its points across all of the evaluation criteria. A ranking of all COTS candidates will be produced to help making the COTS decision. However, often a more focused analysis such as a gap analysis [13] or a business case analysis will be needed.

Besides the above major activities taking place during an assessment process element, there are some other management activities that are necessary and even critical to the assessment result. Such management activities are periodic assessment reviews, including the evaluating team, senior management, customers and the key users. The primary tasks for assessment review are to provide feedback to the evaluation process, to negotiate changes of requirements, design and COTS candidates, to adjust and refine the sets of evaluation criteria, weights, and business scenarios, and make final decisions. The final decisions establish different directions for exiting the

COTS assessment process. We have identified the following three exit directions:

1. Full COTS solution is the best, which means there is a single COTS product or a combination of COTS products covering desired OC&P’s;
2. A partial COTS solution is the best, which means that COTS product(s) only cover part of the OC&P’s, and custom development is needed to meet the gap between COTS and OC&P’s;
3. No COTS products are acceptable, which means that pure custom development is the optimal solution, unless the stakeholders are willing to adjust unsatisfied OC&P’s.

3.3. Tailoring Process Element

In more cases than not the COTS packages may have to be modified slightly in order to satisfy the OC & P’s for the system [12]. If these modifications are directly supported within the COTS packages themselves, then this is considered tailoring activity. The tailoring process element is illustrated in Figure 3.3.

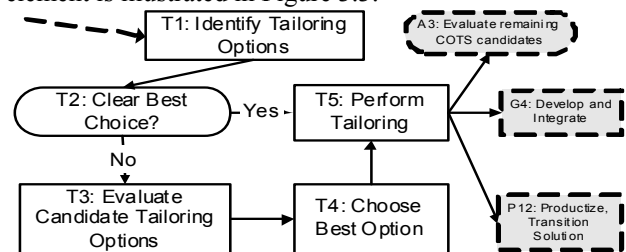


Figure 3.3. The Tailoring Process Element

Entry Conditions for Tailoring

While several COTS products may be tailored simultaneously (often by different people), the tailoring process element focuses on tailoring an individual COTS product. This product may be under consideration by the assessment element; be adapted for use as a glue code component; or be a fully assessed and ready to use product simply needing some specialization. Tailoring may be entered multiple times to accommodate multiple products or refinements to a previously tailored product.

T1: Identify Tailoring Options Identify the candidate options to be used in order to tailor the COTS system. A COTS product may have multiple tailoring options; in such cases the decision must be made as to what capabilities are required to be implemented by which option. As shown in Table 2, tailoring options may include GUI operations, parameter setting, or programming specialized scripts.

T2: Clear Best Choice? If a dominant tailoring COTS tailoring option is found then the developers can proceed to the development of the system. If there are still

multiple tailoring options, the developers need to evaluate them in order to select the best option.

T3: Evaluate COTS Tailoring options. When there is no clear choice from T1 on which tailoring options to pursue, some further evaluation may be necessary. The typical evaluation considerations are: need to implement a particular design, the complexity of tailoring needed, need for adaptability and compatibility with other COTS tailoring choices, and available developer resources. Table 2 summarizes the tailoring option decision factors with respect to these evaluation parameters.

Options Eval. Parameters	GUI based Interface	Parameter Based Interface	Programmable Interface
Design Details Required	Low - None	Low	Detailed
Complexity	Low - Moderate	Moderate	High
Adaptability	Low	Low - Moderate	High
Developer Resources	Low	Low - Moderate	Moderate - High
Example	Real Player	Mr. Sid / Windows Media Player	Browsers - Java Scripts
	Windows Media Encoder		J2EE
	Microsoft Word 2000		

Table 2. Types of Tailoring interfaces and characteristics

3.4. Glue Code Process Element

The intent of a glue code activity is to integrate COTS products as basic application components. In some fortunate cases, the combination of COTS components and application components being integrated or assessed will easily plug-and-play together. If not, some glue code needs to be defined and developed to integrate the components, and some evaluation may be necessary to converge on the best combination of COTS, glue code, and application code for the solution. A number of architectural approaches for using glue code or connectors to integrate COTS products have been developed [16, 17], but less has been done to work out the process for glue code development and its interactions with other CBA processes. Figure 3.4 illustrates the activities and decisions made when working with glue code.

Entry Conditions for Glue Code

The primary entry conditions are a set of components assessed to require glue code for successful joint operation, and a set of exit conditions. When entered from Assessment, the entry criteria also include the assessment criteria, and the exit conditions may be to develop just enough glue code to determine the most acceptable (if

any) combination of components and glue code for a set of evaluation scenarios. When entered from the main decision framework (Fig. 3.1), the exit conditions will be to both determine the best combination of components and glue code, and develop and verify that the combination acceptably satisfies the system OC&P's.

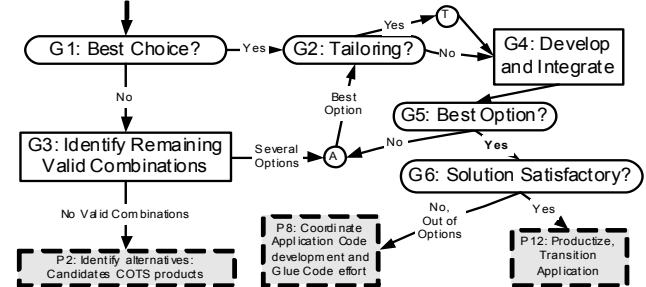


Figure 3.4. The Glue Code Process Element

G1: Best or Only Choice? In this initial decision point determine if there is a clear best choice of viable COTS package (and possible application code) combinations. If so then proceed to tailoring if necessary, otherwise there is a need to evaluate and assess viable combinations.

G3: Identify Valid Combinations. Often COTS packages are attractive from an OC&P standpoint, but cannot be made to feasibly (either technically or economically) interoperate. If none of the candidate packages can feasibly interoperate with respect to the current OC&P's, then more candidates must be generated or the OC&P's must be changed. When there are several valid combinations, the options are to be assessed to identify the best option.

G4: Develop and Integrate. This is the most complex part of the glue code process element. It involves many detailed activities all that must be carefully risk managed. Fortunately there exists a large body of knowledge on the subject of developing and integrating COTS with glue code (such as [16, 17]) and we will not detail them here. The basic tasks are:

1. Determine the interconnection topology options and minimize the complexity of interactions.
2. Evaluate and choose connector options (e.g. events, procedure calls, pipes, shared memory, DB, etc.).
3. Implement the connector infrastructure and develop the appropriate interfaces (simultaneously with application code interfaces if necessary as indicated within the application code process).
4. Integrate the components.

G5: Best Option? It may be that the G4 step produces poorer integrated performance than expected. If so, the G5 step determines whether one of the previously-rejected combinations may be better.

4. Example WinWin Spiral Approach to CBA Development

4.1. Elaborated WinWin Spiral Model

Figure 4.1 provides a more detailed and concise version of the Win Win Spiral Model than that presented in [5]. It returns to the original four segments of the spiral, and adds stakeholders' win-win elements in appropriate places. It also emphasizes concurrent product and process development, verification and validation; adds priorities to stakeholders' identification of objectives and constraints; and includes the LCO, LCA, and IOC anchor point milestones [19] also adopted by the Rational Unified Process.

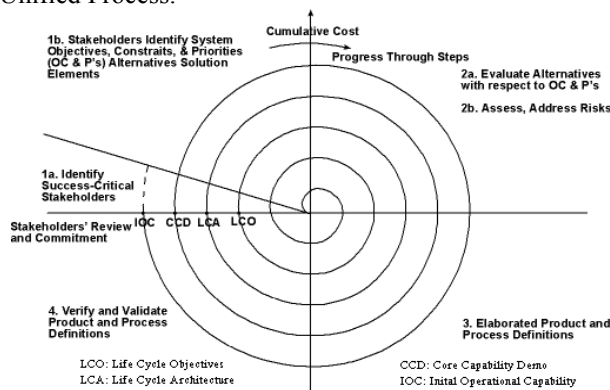


Figure 4.1. Elaborated WinWin Spiral Model

4.2. Example CBA: Oversize Image Viewer

One of the USC e-services COTS-based applications involved the development of a viewing capability for oversized images. The original client needed a system to support viewing of digitized collections of old historical newspapers, but other users became interested in the capability for dealing with maps, art works and other large digitized images. The full system capability included not just image navigation and zoom-in/zoom-out; but image catalog and metadata storage, update, search, and browse; image archive management; and access administration capabilities.

Several COTS products were available for the image processing functions, each with its strengths and weaknesses. None could cover the full system capability, although other COTS capabilities were available for some of these. As the initial operational capability (IOC) was to be developed as a student project, its scope needed to be accomplished by a five-person development team in 24 weeks. The application described in the next section makes some small simplifications of the project for the sake of brevity, but the overall COTS decision sequence and spiral cycles happened largely as described.

4.3. Applying the Decision Framework and the WinWin Spiral Model

The process description provided here for the Oversize Image Viewer (OIV) project covers the project's first three spiral cycles. Each cycle description begins with its use of the WinWin Spiral Model, as the primary sequencing of tasks is driven by the success-critical stakeholders' win conditions and the project's major risk items.

The OIV process description for each cycle then discusses its use of the CBA Process Decision Framework and its process elements. It shows that the framework is not used sequentially, but can be re-entered if the Win Win Spiral risk patterns cause a previous COTS decision to be reconsidered. The resulting CBA decision sequence for the OIV project was a composite process, requiring all four of the Assessment, Tailoring, Glue Code, and Development process elements.

Table 3 provides a spiral model template that is an update of the template used in the original spiral model paper [5]. It shows the major spiral artifacts and activities in the OIV project's first three spiral cycles. The discussion below indicates how these were determined by the major stakeholder OC&P's and project risk items.

4.3.1. Spiral Cycle 1

The original client was a USC librarian whose collections included access to some recently-digitized newspapers covering the early history of Los Angeles. Her main problem was that the newspapers were too large to fit on mainstream computer screens. She was aware that some COTS products were available to do this. She wanted the student developer team to identify the best COTS product to use, and to integrate it into a service for accessing the newspapers' content, covering the full system capability described in section 4.2 above. Lower priorities involved potential additions for text search, usage monitoring, and trend analysis.

Her manager, who served as the customer, had two top-priority system constraints as her primary win conditions. One was to keep the cost of the COTS product below \$25K. The other was to get reasonably mature COTS products with at least 5 existing supported customers.

The student developer team's top-priority constraint was to ensure that the system's Initial Operational Capability (IOC) was scoped to be developable within the 24 weeks they had for the project.

The team quickly used these top-priority constraints to filter out two COTS products: system XYZ was too expensive, and system ABC had only one beta-test customer. The other two OIV COTS products, ER Mapper and Mr. SID, had different user interfaces; the major risk was to select one that users would subsequently find unacceptable. This risk was addressed

by exercising the two products; this stage of the COTS assessment concluded that ER Mapper had considerably stronger performance and image navigation characteristics than Mr. SID. Mr SID's main advantage was that it ran on Windows, Unix, and Macintosh platforms, while ER Mapper was only running on Windows. As the client had a Windows-based operation, ER Mapper was identified as the best candidate. Plans were made to tailor it for the overall product solution, and integrate it with other COTS and/or application code, as ER Mapper was not a complete application solution for such functions as cataloguing and search.

When the customer reviewed these plans, however,

	Cycle 1	Cycle 2 (LCO)	Cycle 3 (LCA)
Stakeholders	Developer, customer, library-user client, COTS vendors	Additional user representatives (Unix, Mac communities)	Additional end-users (staff, students) for usability evaluation
OC&P's	Image navigation, cataloguing, search, archive and access administration COTS cost ≤ \$25K, ≥ 5 user organizations IOC developed, transitioned in 24 weeks	System usable on Windows, Unix, and Mac platforms	Detailed GUI's satisfy representative users
Alternatives	ER Mapper, Mr SID, Systems ABC, XYZ	ER Mapper, Mr SID	Many GUI alternatives
Evaluation; Risks	XYZ > \$25K; ABC < 5 user org's ER Mapper, Mr SID acceptable Risk picking wrong product without exercise	ER Mapper Windows-only; plans to support Unix, Mac; schedule unclear Mr SID supports all 3 platforms Risk of Unix, Mac non-support	Risk of developing wrong GUI without end-user prototyping Mr SID/MY SQL/Java interoperability risks
Risk Addressed	Exercise ER Mapper, Mr SID	Ask ER Mapper for guaranteed Unix, Mac support in 9 months	Prototype full range of system GUI's, Mr SID/My SQL/Java interfaces
Risk Resolution	ER Mapper image navigation, display stronger	ER Mapper: no guaranteed Unix, Mac support even in 18 months	Acceptable GUI's, Mr SID/My SQL/Java interfaces determined
Product Elaboration	Use ER Mapper for image navigation, display	Use Mr SID for image navigation, MySQL for catalog support, Java for admin/GUI support	Develop production Mr SID/My SQL/Java glue code
Process Elaboration	Tailor ER Mapper for library-user Windows client	Prepare to tailor Mr SID, My SQL to support all 3 platforms	Use Schedule as Independent Variable (SAIV) process to ensure acceptable IOC in 24 weeks
Product Process	Customer: want campus-wide usage, support of Unix, Mac platforms ER Mapper runs only on Windows	Need to address Mr SID/My SQL/Java interoperability, glue code issues; GUI usability issues	Need to prioritize desired capabilities to support SAIV process
Commitment	Customer will find Unix, Mac user community representatives	Customer will buy Mr SID Users will support GUI prototype evaluations	Customer will commit to post-deployment support of software Users will commit to support training, installation, operations

Table 3. Spiral Model Application to Oversize Image Viewer

she felt that the investment in a campus OIV capability

should also benefit other campus users, some of whom worked on Unix and Macintosh platforms. She committed to find representatives of these communities to participate in a re-evaluation of ER Mapper and Mr. SID for campus-wide OIV use. The client and developers concurred with this revised plan for spiral cycle 2.

Use of the CBA Decision Framework in Cycle 1

The first three steps of spiral cycle 1 in Table 3 (Stakeholders, OC&P's, Alternatives) include COTS products as alternatives and establish the preconditions (top-level evaluation criteria, weights, and scenarios; candidate COTS products) for entering the CBA Assessment decision framework in Figure 3.1 and 3.2. Spiral step 4 (Evaluation in Table 3) establishes the entry into *Assessment* in Figures 3.1 and 3.2.

Following the Assessment Framework in Figure 3.2, the initial filtering step eliminated some candidates (XYZ and ABC), but not ER Mapper or Mr. SID. The risk assessment in Table 3 required the two COTS products to be exercised, which involved *Tailoring* to accommodate the newspaper image files, but not glue code at this point. The evaluation identified ER Mapper as the best OIV solution, but only as a partial solution for other needed functions such as cataloguing, search, and archiving.

Thus the Assessment process element (Figure 3.2) exits back to the overall CBA decision Framework (Figure 3.1) in the "Partial COTS solution best" direction. But it cannot proceed further until the Win Win Spiral process determines whether either applications code or added COTS products or both need to be developed for the rest of the application (a lower risk decision deferred to a subsequent spiral cycle).

However, spiral cycle 1 ended with a new decision to revisit *Assessment* with likely new OC&P's emerging from other-OIV-user stakeholders as evaluation criteria. Thus we can see that the CBA decision framework is not sequential, but needs to be recursive and reentrant depending on risk and OC&P decisions made within the Win Win Spiral process.

4.3.2. Spiral Cycle 2

With the new Unix and Mac OIV stakeholders, a new win-win set of OC&P's emerges, including not only Unix and Mac OIV usability but also interoperability with other selected COTS products on all three platforms. The new evaluation/COTS assessment confirmed that Mr. SID was usable on all three platforms, but that ER Mapper had only general plans for Unix and Mac versions.

When ER Mapper declined to guarantee early Unix and Mac versions, Mr. SID became the new choice for the OIV functions. Concurrent assessment of candidate COTS products for the non-OIV functions converged on MySQL for catalog database support and Java for GUI support. Although the initial evaluation indicated that

these were interoperable with Mr. SID, a fully interoperable build-upon (vs. throwaway) prototype was scheduled to be developed and interoperability-verified in spiral cycle 3. The other outstanding risk identified was that the system's GUI needed prototyping with additional end-user representatives also planned for spiral cycle 3.

Spiral cycle 2 ended with a WinWin Spiral LCO (Life Cycle Objectives) milestone review. At the LCO review, all of the stakeholders agreed to support the commitments allocated to them in the plans.

Use of the CBA Decision Framework in Cycle 2

The new stakeholders and OC&P's in cycle 2 required the project to backtrack to the beginning of the Assessment process element in Figure 3.1 and 3.2. For the OIV function, ER Mapper was filtered out without further evaluation when it declined to guarantee early Unix and Mac versions. Some tailoring was required to verify that Mr. SID performed satisfactorily on Unix and Mac platforms.

Concurrently, *Assessment* filtering and evaluation tasks were being performed for the cataloging and GUI functions.

This concurrency is a necessary attribute of most current and future CBA processes. Simple deterministic process representations are simply inadequate to address the dynamism, time-criticality, and varying risk/opportunity patterns of such CBA's. However, the Win Win spiral process provides a workable framework for dealing with risk-driven concurrency, and the composable CBA decision framework and process elements provide workable approaches for handling the associated CBA activities. The dynamism and concurrency makes it clear that the CBA process elements need to be recursive and reentrant, but they provide a much-needed structure for managing the associated complexity.

4.3.2. Spiral Cycle 3

The additional end-user stakeholder communities increased the risk of developing GUI's that were fine for some users and unsatisfactory to others. These risks were resolved by involving representative end users in exercising GUI prototypes for various cataloging, search, and navigation functions. The major CBA processes involved the *Assessment* of detailed interoperability characteristics of Mr. SID, MySQL, and the GUI software on the Windows, Unix, and Mac platforms. This involved invocation of both the *Tailoring* and *Glue Code* process elements.

The other major risk was the fixed 24-week IOC development schedule. This was handled via the Schedule as Independent Variable (SAIV) process described in [18]. The SAIV process requires customers and users to prioritize their desired capabilities. The

priorities are used to define a core capability clearly buildable within the fixed schedule, and to architect the application for ease of adding or dropping borderline-priority features. This approach was satisfactory to the stakeholders, and resulted in a successfully transitioned Initial Operational Capability at the end of the 24 weeks.

Use of the CBA Decision Framework in Cycle 3

The Assessment process for interoperability of Mr SID, My SQL, and the Java GUI components on the Windows, Unix, and Mac platforms did not involve a comparative evaluation of alternative COTS products, although alternatives would have been necessary in case one of the COTS products had proved completely inadequate. The interoperability assessment involved both tailoring of the COTS products for the three platforms and some glue code to (successfully) enable interoperability.

Subsequent spiral cycles to develop the core capability and the IOC did not involve further Assessment, but involved concurrent use of the Tailoring, Glue Code, and custom development processes.

4.4. Summary of CBA Decision Framework Use

The use of the CBA decision framework during the three spiral system definition cycles and the subsequent development activity can be summarized by the sequence A, T; (AA); A, (TG); (TGC). The first spiral cycle involved Assessment supported by Tailoring. The second cycle involved two concurrent pure Assessments for the OIV COTS choice and for the other COTS choices. The third cycle involved an interoperability Assessment supported by concurrent Tailoring and Glue Code processes. The final development activity involved concurrent Tailoring, Glue Code, and custom development processes.

5. Conclusions

The fraction of projects that are COTS-based applications (CBA's with over 30% of end-user functionality provided by COTS and over 10% of development effort devoted to COTS considerations) is rapidly increasing in many application sectors. A 5-year longitudinal analysis of similar small e-services applications showed a growth from 28% CBA's in 1997 to 60% in 2001.

For samples of both small and large CBA's we have analyzed, most COTS-specific effort was devoted to COTS Assessment (A), Tailoring (T), or Glue code (G) activities. There is no one-size-fits-all distribution of A, T, and G effort, although there are some common patterns and significant correlations (e.g., a -.92 negative correlation between amount of Tailoring effort and Glue code effort).

Not only waterfall processes, but also standard object-oriented, UML-based processes have significant difficulties in dealing with the uncontrollable COTS architecture constraints, COTS dynamism, COTS uncertainty, and concurrency of activities involved in developing CBA's.

Our CBA project analysis found that for the most part, "where the effort happens, there the process happens." We also found that the Assessment, Tailoring, and Glue code activities followed similar processes for these elements. These A, T, and G process elements, and a custom application-code construction process element (C), could be composed into an overall process decision framework for CBA's.

However, there was also no one-size-fits-all path through the decision framework. In fact, most CBA processes we have analyzed are dynamic and concurrent, and the process elements need to be reentrant and recursive.

Using the WinWin Spiral Model's risk-driven approach coupled with the CBA decision framework as a process model generator, however, enabled projects to generate appropriate combinations of A, T, G, and C process elements that best fit their project situation and dynamics. An extensive discussion of its application to an actual CBA project is provided as an example.

The resulting combinations of A,T,G, and C elements serve as a sort of genetic code for the projects CBA process which can be used to identify and compare it with other projects CBA processes. The analogy can be stretched too far, but it suggests several attractive directions for future research, such as determining how best to represent the concurrency and backtracking aspects; validating and refining effort distributions based on process elements; assessing the validity of the process elements and decision framework in other CBA sectors; and identifying common process element configurations, valid and invalid configurations, or large-grain CBA process patterns.

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