Smart Buying with the Federal Aviation Administration's Integrated Capability Maturity Model[sm]

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The Federal Aviation Administration (FAA) has developed an integrated Capability Maturity Model[sm] for the acquisition of software intensive systems. This model, known as the FAA-iCMMâ, integrates the Systems Engineering Capability Maturity Model (SE-CMM v1.1), the Software Acquisition CMM (SA-CMM v1.01) and the CMM for Software (SW-CMM v1.1). The FAA-iCMM is guiding the improvement of FAA-wide processes used to manage, acquire, and engineer software intensive systems across the FAA acquisition life cycle from mission analysis to service life extension. The FAA is achieving more effective and efficient processes and process improvement by using the integrated model, rather than the 3 source CMMs separately.

This paper describes the FAA's process improvement environment and why the FAA-iCMM was constructed. The model is presented including its architecture, domain, capability levels, maturity levels, and the FAA-iCMM Appraisal Method. Lastly, the FAA's iCMM-based process improvement initiative is described.

Overview of the FAA CMM Integration Project

The FAA developed the FAA Integrated Capability Maturity Model[sm] (FAA-iCMM®) to guide improvement of the engineering, management, and acquisition processes it uses in acquiring software intensive systems. Three Capability Maturity Models (CMMs) had been being used separately in different FAA directorates that work on different aspects of acquisition: the CMM for Software [SW-CMM], the Systems Engineering CMM [SE-CMM], and the Software Acquisition CMM [SA-CMM]. These CMMs have different architectures, goals, terminology, and appraisal methods and none alone covers all FAA system acquisition activities. While some improvements were being made using one model, the goal of FAA-wide, full lifecycle, process improvement remained elusive. In addition, the FAA had moved to using integrated product teams as the implementation arm for its new Acquisition Management System [AMS] and these teams needed processes that interrelated their disciplines.

The FAA-iCMM initiative began in the fall of 1996 with an analysis and preliminary merger of these 3 CMMs at the process area level. One sample process area was also elaborated at the base practice level [Ibrahim 96a,

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[sm] Capability Maturity Model is a service mark of Carnegie Mellon University. CMM® is registered in the U.S. Patent and Trademark Office.

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96b]. These efforts demonstrated that it was possible to integrate CMMs of different architectures and that the resultant model contained a significant reduction in the number of process areas and practices while still covering the individual CMM disciplines.

In March 1997, the FAA formed a team of FAA and external CMM and domain experts and began work on the integrated model. The project purpose was to derive a reference model that would: describe key elements of an effective system acquisition process, describe an evolutionary improvement path, have an associated appraisal method, and faithfully and robustly capture all features of its 3 source CMMs (SA-CMM, SE-CMM, and SW- CMM). Meanwhile, the Software Engineering Institute (SEI) of Carnegie Mellon University commenced development of a Common CMM Framework [CCF] whose purpose was to provide guidance to multiple CMM users and to assist CMM developers and integrators. The FAA-iCMM project followed those draft guidelines as they continued to evolve in parallel with FAA efforts.

A complete draft of the FAA-iCMM was completed by June 1997 and submitted to the SEI for review. FAA management adopted an FAA-iCMM-related performance goal that same month. In late September, a joint SEI-FAA review/working session was held to ensure consensus that the FAA's work captured its source CMMs and followed CMM principles, construction guidelines, and requirements as identified in the latest draft CCF documents. Version 1.0 of the FAA-iCMM was released in November 1997 with endorsement by the SEI as a new product type - an iCMM (integrated Capability Maturity Model).

General CMM Integration Decisions

What to integrate (Scope)

The FAA chose to integrate the 3 CMMs, which were already in FAA, use, and which together covered the engineering, acquisition, and management processes used by the FAA for acquiring software intensive systems. The Integrated Product Development CMM was briefly considered but the draft model did not seem stable enough for inclusion at that time. The various drafts of SW-CMM version 2.0 were also coming out, but the FAA decided to use validated versions of the source CMMs to the extent possible for the initial version of the model.

How to represent the model (CMM architecture)

The FAA chose to use a hybrid architecture that includes both the continuous and staged features of its source CMMs (see Table 1). Through this "continuous with staging" architecture, the FAA- iCMM provides guidance for improving both process capability and organizational maturity. As in a continuous representation, the FAA-iCMM describes the domain aspect (e.g. process areas and base practices) separately from the capability aspect (capability levels and generic practices). This feature of the continuous representation provides guidance to improve any of its process areas to any capability level desired (from 1 to 5). In addition, goals were added to both process areas and capability levels. The FAA-iCMM also provides staging that groups the process areas and generic practices into maturity levels. This feature provides guidance regarding improving organizational maturity, and regarding "what to focus on next" if needed. It also allows a summary rating of an organization's process maturity (from 1 to 5), if needed. For more information on architecture conversion issues, please refer to [Ibrahim 98a, 98b].

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FAA-iCMM (v 1.0) (continuous with staging)	*SA-CMM (v1.01) and SW-CMM (v1.1) (staged)*	*SE-CMM (v1.1) (continuous)*
Domain Aspect: Implementation (What you do)		
Process Areas (PAs)	Key Process Areas	Process Areas
Purpose	Purpose	Purpose
Process Area Goals	Goals	-
Base practices (BPs)	Key practices of the "Activities performed" Common Feature	Base practices
Process Capability: Institutionalization (How well you perform a process area)		
Capability Levels	-	Capability Levels
Capability Level Goals	-	-
Generic Practices (GPs)	Key practices of the "Commitment to Perform" "Ability to Perform" "Measurement and Analysis", and "Verifying Implementation" Common Features	Generic Practices
Staging: Organizational Maturity (What to focus on next)		
Maturity levels	Maturity levels	-

Appraisal note: The FAA-iCMM Appraisal Method (FAM) uses process area goals and capability level goals as the major rating components during an appraisal. Maturity levels are optionally derived from capability level ratings, according to the FAA-iCMM definition of maturity level.

Table 1. FAA-iCMM Architecture Summary: Architectural Constructs across the Source Models

Traceability

In order to satisfy its robustness, fidelity, and traceability requirements, the FAA-iCMM contains extensive tracing tables. These tables are at the process area level as well as the practice level and are included as part of each process area and base practice description. Additionally, complete mapping tables are provided in an appendix that enables a reader to locate where any practice in any of the source models is mapped in the FAA-iCMM. (See [FAA-iCMM]).

Overview of the Model

The FAA-iCMM is structured to answer 3 process improvement questions: what activities should be performed (the domain aspect), how can performance be improved (the capability aspect), and what processes should be focused on next (maturity levels). The FAA-iCMM Appraisal Method supports application of the model. Each aspect is briefly described below.

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The Domain Aspect

The domain is the acquisition of software intensive systems. There are 23 process areas derived from integrating the 52 process areas/key process areas of the 3 source CMMs. These process areas are grouped into 4 categories: life cycle or engineering, management or project, supporting, and organizational process areas. Table 2 shows the 23 process areas of the FAA-iCMM along with the major sources that were used to derive each process area.

FAA-iCMM v1.0 Process Area	***Systems Engineering SE-CMM v 1.1 Process Area***	***Software Acquisition SA-CMM v1.01 Key Process Area***	***Software Engineering SW-CMM v1.1 Key Process Area***
Life Cycle or Engineering Processes			
PA01 Needs	Understand Customer Needs & Expectations	-	-
PA02 Requirements	Derive & Allocate Reqmts	Requirements Dev & Mgmt	Requirements Management *(*SW Product Engineering)*
PA03 Architecture	Evolve System Arch	-	*(*SW Product Engineering)*
PA04 Alternatives	Analyze Cand. Solts	-	-
PA05 Outsourcing	Coord. w Suppliers	Solicitation	SW Subcontract Mgmt
PA06 Software Dev/ maintenance	-	-	SW Product Engineering
PA07 Integration	Integrate System	-	
PA08 System Test and Evaluation	Verify &Validate System	Evaluation	
PA09 Transition	-	Transition to Support	-
PA10 Product Evolution	Manage Product Line Evolution	-	-
Management or Project Processes			
PA11 Project Management	Plan Technical Effort Monitor & Control Technical Effort	SW Acquis. Planning Project Management Project Perf Mgmt	SW Project Planning SW Project Track & Overst Integrated SW Mgmt
PA12 Contract Management	*(* Coordinate with Suppliers)*	Contract Track& Osight Contract Perf Mgmt	SW Subcontract Mgmt
PA13 Risk Mgmt	Manage Risk	Acquisition Risk Mgmt	*(*Integrated SW Mgmt)*
PA14 Coordination	Integrate Disciplines		Intergroup Coordination
Supporting Processes (not lifecycle phase dependent)			
PA15 Quality Assurance & Mgmt	Ensure Quality		SW Quality Assurance
PA16 Config Mgmt	Manage Config		SW Config Mgmt
PA17 Peer Review	Lev3 Common Features		Peer Reviews
PA18 Measurement	Lev4 Common Features	Quant Process Mgmt Quant Acquis Mgmt	Quantitative Process Mgmt SW Quality Management
PA19 Prevention	Lev5 Common Features	-	Defect Prevention
Organizational Processes			
PA20 Org Process Definition	Define Org's Systems Eng Process	Process Definition & Maintenance	Org. Process Focus Org. Process Definition
PA21 Org Process Improvement	Improve Org's Systems Eng Process	Continuous Process Improvement	Process Change Mgmt

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FAA-iCMM v1.0 Process Area	*Systems Engineering SE-CMM v 1.1 Process Area*	*Software Acquisition SA-CMM v1.01 Key Process Area*	*Software Engineering SW-CMM v1.1 Key Process Area*
PA22 Training	Provide Ongoing Skills & Knowledge	Training Program	Training Program
PA23 Innovation	Manage Systems Eng Support Environment	Acquisition Innovation Mgmt	Technology Change Mgmt

*Some of the practices in this process area contributed to the practices integrated into the FAA-iCMM process area

Table 2. The Integrated Process Areas of the FAA-iCMM

Each process area description includes a purpose, goals, and from 2 to 10 fully elaborated base practices. Some excerpts from the Requirements Process Area (PA 02) are provided in Table 3.

PA 02: Requirements

Purpose

The purpose of the Requirements process area is to develop requirements to meet the customer's operational need, to analyze the system and other requirements, to derive a more detailed and precise set of requirements, and to manage those requirements throughout the acquisition life cycle.

Goals

1. Requirements are derived from customer needs and other appropriate sources. *(BP 02.01, BP 02.02, BP 02.03, BP 02.04)*
2. Requirements are allocated to support the synthesis of solutions. *(BP 02.05)*
3. Requirements are unambiguous, traceable, and verifiable. *(BP 02.06, BP 02.09)*
4. Requirements are controlled to establish a baseline for engineering and management use. *(BP 02.07, BP 02.09)*
5. Plans, products, and activities are kept consistent with requirements. *(BP 02.08, BP 02.09)*

Base Practice List

BP 02.01	**Develop detailed operational concept**: Develop a detailed operational concept of the interaction of the system, the user, and the environment, that satisfies the operational need.
BP 02.02	**Identify key requirements:** Identify key requirements that have a strong influence on cost, schedule, functionality, risk, or performance.
BP 02.03	**Derive and partition requirements:** Derive and partition requirements that may be logically inferred and implied as essential to system effectiveness, from the system and other (e.g., environmental) requirements.
BP 02.04	**Identify interface requirements:** Identify the requirements associated with external interfaces to the system and interfaces between functional partitions or objects.
BP 02.05	**Allocate requirements:** Allocate requirements to functional partitions, objects, people, or support elements to support synthesis of solutions.
BP 02.06	**Analyze requirements:** Analyze requirements to ensure that they can be implemented, verified, and validated by methods available to the development effort.
BP 02.07	**Capture and baseline requirements:** Capture, baseline, and place under change control the system and other requirements, derived requirements, derivation rationale, allocations, traceability, and requirements status.
BP 02.08	**Analyze and incorporate requirements changes**: Analyze all requirements change requests for impact on the product being acquired and upon approval, incorporate the approved changes into the product, work plans, and activities.
BP 02.09	**Maintain consistency and traceability:** Maintain consistency and traceability among requirements and between requirements and plans, work products, and activities.

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Table 3. Purpose, Goals, and Base Practice List of the Requirements Process Area of the FAA-iCMM

The Capability Aspect

There are 5 capability levels in the FAA-iCMM, and generic practices at each level provide guidance for improving any process. Generic practices are additive as process capability increases through the 5 levels. The capability levels, their goals, and their generic practices are summarized in Table 4.

Level 1: Initial: Performed Informally	*Description:* Base practices of the process area are generally performed. *Generic Practice:* 1.1 Perform the process
Level 2: Repeatable: Planned & Tracked	*Description:* Basic management processes are established. The necessary process discipline is in place to repeat earlier successes with similar work processes. Performance of the base practices in the process area is planned and tracked. *Goal:* The activities for the process are institutionalized to support a repeatable process. *Generic Practices*: 2.1 Establish policy 2.2 Allocate adequate resources 2.3 Assign responsibility 2.4 Ensure training 2.5 Document the process 2.6 Plan the process 2.7 Use a repeatable process 2.8 Manage configurations 2.9 Assess process compliance 2.10 Verify work products 2.11 Measure process 2.12 Review status 2.13 Take corrective action 2.14 Coordinate within the project
Level 3: Defined: Well Defined	*Description*: Base practices are performed according to a well-defined process using approved, tailored versions of standard documented processes. *Goal*: The activities of the process are institutionalized to support a defined process. *Generic Practices*: 3.1 Standardize the process 3.2 Use defined process 3.3 Perform reviews with peers 3.4 Coordinate with affected groups

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Level 4: Managed: Quantitatively Controlled	*Description:* Processes and products are quantitatively measured, understood, and controlled; detailed measures of performance are collected and analyzed. *Goal:* The activities of the processes are institutionalized to support quantitative management of defined processes. *Generic Practices:* 4.1 Establish quality objectives for product and process 4.2 Select processes for measurement 4.3 Select measures for the process 4.4 Determine quantitative process capability 4.5 Use quantitative process capability
Level 5: Optimizing: Continuously Improving	*Description:* Continuous process improvement is enabled by quantitative feedback from the process and from piloting innovative ideas and technologies. A focus on widespread, continuous improvement permeates the organization. The organization establishes quantitative performance goals for process effectiveness and efficiency based on its business goals. *Goal:* Continually improving processes are deployed throughout the organization. *Generic Practices:* 5.1 Perform continual process improvement on the organizational standard and tailored processes 5.2 Implement improved processes

Table 4. Capability Level Summary

Maturity Levels

Maturity levels in the FAA-iCMM are groupings of process areas and generic practices. They "stage" the process areas to provide guidance for improving organizational maturity. Maturity levels are conceptually the same as capability levels, i.e. the same 5 levels are employed, but they provide guidance on what processes together contribute to each step of organizational maturity. Maturity levels are described in Table 5.

Level 2 Process Areas. Level 2 is the Repeatable or Planned and Tracked Level. The following process areas are grouped at maturity level 2: *Lifecycle/Engineering Processes* PA 01 Needs, PA 02 Requirements, PA 05 Outsourcing, PA 08 System Evaluation, PA 09 Transition *Management/Project Processes* PA 11 Project Management, PA 12 Contract Management *Supporting Processes* PA 15 Quality Assurance & Management, PA 16 Configuration Management For an organization to have level 2 maturity, the above process areas should be at level 2 (or higher) capability according to an FAA-iCMM appraisal. This would indicate a "level 2" organizational maturity.
Level 3 Process Areas. Level 3 is the Defined or Well Defined Level. The following process areas are grouped at maturity level 3: *Lifecycle/Engineering Processes* PA 03 Architecture, PA 04 Alternatives, PA 06 Software Development and Maintenance, PA 07 Integration *Management/Project Processes* PA 13 Risk Management, PA 14 Coordination *Supporting Processes* PA 17 Peer Review *Organizational*

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PA 20 Organization Process Definition, PA 22 Training For an organization to have level 3 maturity, all level 2 process areas plus all level 3 PAs should be at level 3 (or higher) capability according to an FAA-iCMM appraisal. This would indicate a "level 3" organizational maturity.
Level 4 Process Areas. Level 4 is the Managed or Quantitatively Controlled Level. The following process areas are grouped at maturity level 4: *Lifecycle/Engineering Processes* PA 10 Product Evolution *Supporting Processes* PA 18 Measurement For an organization to have level 4 maturity, all level 2, 3, and 4 process areas of the FAA-iCMM should be at capability level 4 (or higher) according to an FAA-iCMM appraisal. This would indicate a "level 4" organizational maturity.
Level 5 Process Areas. Level 5 is the Optimizing or Continuously Improving Level. The following process areas are grouped at maturity level 5: *Supporting Processes* PA 19 Prevention *Organizational Processes* PA 21 Organization Process Improvement, PA 23 Innovation For an organization to have level 5 maturity, all process areas of the FAA-iCMM should be at capability level 5 according to an FAA-iCMM appraisal. This would indicate a "level 5" organizational maturity.

Table 5. Maturity Level Summary

Appraisal method

FAA developed the FAA-iCMM Appraisal Method (FAM) which includes several variations. The full internal appraisal is similar to the CMM-Based Appraisal for Internal Process Improvement [CBA-IPI] method, except it has been adapted to a continuous model with both process area goals and capability level goals. Other appraisal types include facilitated discussion, training-based, document-intensive, questionnaire-based, interview-intensive, and external appraisal (for use by external agencies that may want to appraise the FAA's process capability). These appraisal types draw on and adapt from several appraisal methods such as the SE-CMM Appraisal Method [SAM], Software Capability Evaluation [SCE], and Interim Profile [IP]. Again, FAA's concept is to integrate and draw together various appraisal methods, just as it integrated its source CMMs. All FAM variations are tailorable and cover needs for initial, interim or full appraisal.

Using the Model

The FAA's CMM integration goals are to increase the efficiency and effectiveness of FAA processes and process improvement efforts. Increased efficiency is being realized by reducing the number of process areas from 52 in the separate models to 23 in the integrated model, by replacing separate training and appraisals against 3 CMMs with efforts against one model, and by replacing largely redundant efforts to improve similar processes with a single effort to improve an integrated process. Increased effectiveness is being realized

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through development of processes that cover all FAA acquisition life cycle phases, and that integrate the management, engineering, and acquisition activities of an integrated product team.

FAA management adopted the FAA-iCMM by setting an aggressive improvement goal for FAA's major software-intensive programs to achieve maturity level 2 by December 1999, and level 3 by December 2001. In the first 6 months of FAA-iCMM usage, about 600 managers and practitioners were trained, and about 20 programs (including the targeted "major" programs, plus programs voluntarily signing up) are using the model to guide their process improvement. FAA-iCMM process improvement workshops and appraisals are finding that the model raises and promotes resolution of process integration issues across the disciplines and across the acquisition lifecycle. Working to improve the Requirements and the Transition process areas for example (both staged at maturity level 2) has required extensive cross-directorate, cross-discipline, cross-lifecycle participation.

A major appraisal is currently being planned to determine interim status, to facilitate process improvement plan adjustment, and to promote even broader discussions and learning about process improvement. Meanwhile, the FAA process improvement goal is being strengthened to include new programs as they are initiated.

Other government organizations, including Warner Robins Air Force Base and the Internal Revenue Service have received FAA-iCMM training and are looking towards adopting an integrated approach to process improvement. Several companies, including Lockheed Martin, have also expressed interest.

Other models may be included in future versions of the FAA-iCMM, (such as models generated from the Government-Industry-SEI Capability Maturity Model Integration [CMMI] project or the Systems Security Engineering CMM) and other disciplines (including Human Factors) are being studied for inclusion now. The model is available in the public domain for organizations seeking to improve their acquisition processes.

Summary and Conclusions

Capability Maturity Models provide valuable guidance to organizations committed to process improvement. When an organization needs to use multiple CMMs to cover its business needs however, CMM-based process improvement can become costly and confusing because of the differences in CMM architecture, terminology, appraisal methods, etc. The FAA endeavored to solve this problem by integrating three CMMs into the FAA-iCMM, thereby reducing overlap and redundancies yet capturing the features of all 3 models. Following the latest CMM integration guidance available, the FAA-iCMM is the first proof of concept that CMM integration can work. This integrated CMM can be used to improve the processes used by system engineers, software engineers, and acquisition practitioners as they work together in integrated product teams to acquire systems. For acquisition organizations, the FAA-iCMM provides guidance for smart buying.

Author Biography

Dr. Linda Ibrahim is the process improvement lead at the Federal Aviation Administration. She chairs the Corporate Software Engineering Process Group (SEPG) and she is the Project Leader, architect, and lead author on the FAA's CMM Integration Project (the FAA-iCMM project). She is a member of the Steering Group for the government-industry-SEI CMM Integration (CMMI) effort. Linda has been working in software engineering for more than 30 years. She was a Senior Member of the Technical Staff for several years at the Software Engineering Institute, and other previous employers include corporations, universities,
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