2006 IEEE Aerospace Conference
Track 13 Session 13.03

Advancing the Practice of Systems Engineering at JPL

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Systems Engineering Advancement (SEA) Project
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Topics To Be Covered

- SEA General Approach
  - Mission of the SEA Project
  - Scope of Systems Engineering at JPL
  - SEA Target Audience
  - Systems Engineering Disciplines
- Three Key Components of Change: People, Process and Technology
- **People** Component
- **Process**: Systems Engineering Practices
- **Technology**: Model-Based Engineering
- Backup Slides
  - Customer Relationship Management (CRM)
  - Organizational Change Management (OCM)
  - Lessons Learned

The work described in this paper was performed at the Jet Propulsion Laboratory, California Institute of Technology under a contract with the National Aeronautics and Space Administration (NASA).

Mission of the SEA Project

- The mission of the Systems Engineering Advancement (SEA) Project is:
  - To measurably improve the practice of systems engineering at JPL,
  - To contribute to increasing efficiency and decreasing the risk associated with the development and operation of JPL's flight projects,
  - To ensure there is a pipeline of qualified systems engineers with the critical skills needed now and for future missions.

Scope of Systems Engineering at JPL

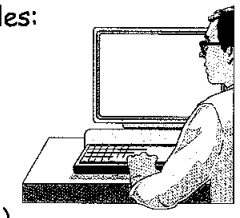
- Technical Scope: The systems engineering process is defined to include 10 technical functions:
  1. Develop System Architecture
  2. Develop & Maintain Requirements
  3. Develop & Maintain Interfaces
  4. Manage Technical Resources
  5. Analyze & Characterize the Design
  6. Verify & Validate
  7. Manage Risk
  8. Conduct Reviews
  9. Manage & Control the Design
  10. Manage the SE task

SE is practiced across the full life-cycle, technical scope and at all levels in a flight project.

- Systems Engineering Levels
  - Level 1 - Program
  - Level 2 - Project
  - Level 3 - System (Flight, Ground and Launch)
  - Level 4 - Subsystem (Avionics, Electrical Power, Instrument, Mechanical, Propulsion, Telecommunications, Thermal, Software, etc.)
  - Level 5 - Assembly or Element
- Full System Life-Cycle
  - Pre-Phase A - Advanced Studies
  - Phase A - Mission and System Definition
  - Phase B - Preliminary Design
  - Phase C - Design and Build
  - Phase D - Assembly, Test and Launch Operations (ATLO)
  - Phase E - Operations

SEA Customers (Target Audience)

- JPL's Systems Engineering Community consists of approximately 900 people (out of 5500 lab-wide).
- SEA customers primarily include the following roles:
  - Program Systems Engineers
  - Project Systems Engineers
  - Flight/Spacecraft Systems Engineers
  - Ground Data System (GDS) Systems Engineers
  - Mission Ops Systems (MOS) Systems Engineers
  - 16 other Level 4 SE Disciplines (including Software)
- Managers in JPL Line organizations:
  - Section Managers and Technical Group Supervisors
- Managers in JPL Program/Project offices:
  - Program Managers and Project Managers
  - Mission Assurance Managers (MAMs)
- Any others whose decisions impact the way systems are developed or acquired



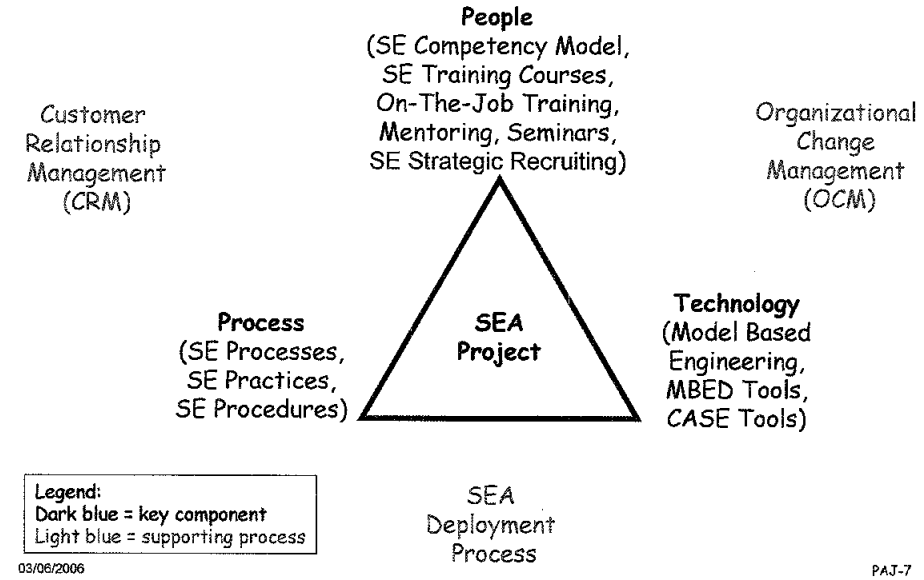
Systems Engineering Disciplines

- Program SE
- Project SE
- Flight/Spacecraft SE
- Ground Data System (GDS) SE
- Mission Ops Systems (MOS) SE

Level 4 SE Disciplines

- Avionics SE
- Deep Space Network SE
- Entry, Descent & Landing (EDL) SE
- Guidance, Navigation & Control (GN&C) SE
- Instrument/Payload SE
- Mechanical Subsystem SE
- Planning & Execution SE
- Power SE
- Propulsion SE
- Radar SE
- Telecom SE
- Tracking Systems SE
- Thermal/Fluid SE
- Uplink SE
- Project Software SE
- Software SE

Three Key Components of Change



People Components

- Systems Engineer Competency Model
- Elements of SE Training
- SEA On-the-Job Training (OJT) Program
- SEA Seminar Series

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Systems Engineer Competency Model

This model will be used to:
- Screen candidates for external hire
- Conduct internal assessments
- Drive training content
- Perform active career management

Personal Behavior

Leadership Skills
- Has the ability to influence
- Has the ability to work with a team
- Has the ability to trust others
- Communicates vision and technical steps needed to reach implementation
- Mentors and coaches less experienced systems engineers

Attitudes and Attributes
- Has intellectual self-confidence
- Has intellectual curiosity
- Has ability to manage change
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Communication
- Advances ideas and fosters open two-way discussions
- Communicates through storytelling and analogies
- Listens and translates information

Problem Solving and Systems Thinking
- Manages risk
- Thinks critically and penetrates a topic in a methodical manner

Process

• Has proven knowledge of systems engineering practices (JPL's 10 SE functions)

• Expresses a technical grasp of system engineering at all levels
• Is a generalist in nature, with proven technical depth in 1 or 2 SE disciplines
• Knowledge is unique to each SE discipline e.g., Flight System, MOS, Radar, Avionics, Software, . . .

Technical Knowledge

Personal Training is planned in **EACH** axis depending upon what the individual brings to the assignment and the content of the assignment.

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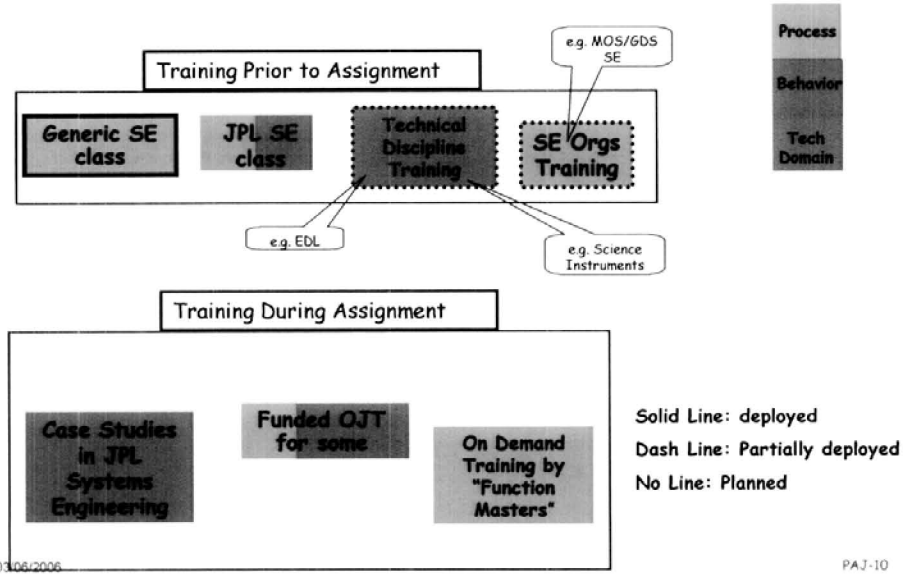
Elements of SE Training



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SEA On-The-Job Training (OJT) Program

Criteria for SEA OJT Candidates

1. **Career Phase**: Are in early or mid career phase
2. **Potential**: Have the potential of being the best SE in their organization
3. **SE Ability**: Are able to implement the SE functions
4. **SE Behaviors**: Have many of the preferred SE behaviors
5. **Experience**: Have had delivery experience [Cog E or ATLO] and SE work experience
6. **SE Disciplines**: Are representative of a cross section of the 21 systems engineering disciplines at JPL
   - Note: Items 2-4 above are expected to be enhanced via training and OJT experiences

- Each year 10 candidates will receive personalized investment and training
  - Five year duration of OJT Program means total of 50 SEs trained
- Protégés should work on, or should be able to be placed on, a major flight project.
- Protégés need a mentor on the project.
- Protégés will average 32 hours per week for their project and will average 8 hours per week on:
  - Shadowing, SE classes, other project reviews, time with mentor and SE function masters, etc.

SEA Seminar Series

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01/06/2006	Tying Requirements To Design Artifacts	H. Clark Briggs	47
		Total Attendees	1292

Process: Development of JPL Systems Engineering Practices

- What:
  - A body of requirements on how JPL practices systems engineering
    1. Develop System Architecture
    2. Develop & Maintain Requirements
    3. Develop & Maintain Interfaces
    4. Manage Technical Resources
    5. Analyze & Characterize the Design
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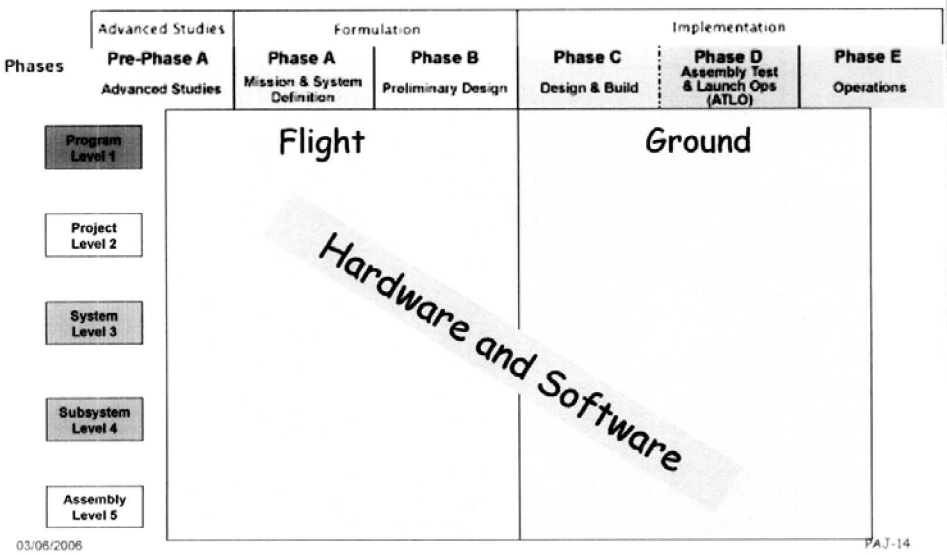
  - ~10 reqs for each of the Systems Engineering Functions
- Why:
  - Reduce development and operations risk of our flight projects
  - There is no JPL SE "standard"
  - Improve the efficiency of the implementation of systems engineering
  - Become aligned with NASA requirements and professional "best practices"
- Who:
  - Practitioner "Blue Teams" led by SE Function Masters
  - Critical "Red Team" representing program directorates
- How:
  - Reviewed 14 SE standards and used as "seed material' for SE practices
    - INCOSE, IEEE, NASA SE NPR, GSFC SE Directive,...

Scope of Systems Engineering Practices



Technology: Model Based Engineering

1. **Conducted Systems Engineering Tool Comparison**
   - **Four Comparison areas:**
     - **Architecture & Design Modeling, Executable Modeling & Simulation, Information Management, and Administration & Usage**
   - **Functional Modeling Tools**
     - CORE - Vitech Corporation http://www.vtcorp.com
     - Cradle - 3SL http://www.threesl.com
   - **UML/SysML Tools**
     - Real-time Studio - Artisan Software http://www.artisansw.com
     - Rhapsody - I-Logix http://www.ilogix.com
     - TAU - Telelogic http://www.telelogic.com
   - **Other**
     - TeamCenter Requirements - UGS http://www.ugs.com
2. **Formed UML/SysML Users Group**
   - **Held inaugural meeting on Jan. 12, 2006 and created website**

Technology: Model Based Engineering (Cont.)

3. **Created JPL Flight Project Schema Definition v0.1**
   Objective: A schema that can be used by flight projects to capture all of their information at all levels of abstraction
   - **Requirement, Function, Product, Interface, Process, Timeline, Issue, State, Use Case, Descriptive Text, External, Standard, Resource**
4. **Planning lab-wide model based engineering workshop**

Summary

1. Changes in how systems are managed, developed and acquired do not come quickly or easily.
2. The improvement process needs to be approached with many of the same deliberate methods and practices that are used in actual system development.
3. It is essential to proactively reach out to customers instead of merely waiting for them to come to you.
4. It is important to maintain the proper balance between defining processes and generating assets vs. actually deploying them and supporting customers.
   - If this balance is not achieved, all the products generated just become "shelfware."
5. All three aspects of change management must be addressed – people, process and technology – and the people component is where the maximum leverage is gained.
   - Knowing how successful systems engineers behave and sharing that information with the SE community establishes a standard for hiring, evaluation and personnel development.

Backup Slides

Customer Relationship Management

- The SEA Project took a proactive approach to Customer Relationship Management (CRM).
  - An approach not usually invoked in an engineering environment.
- CRM is a strategy used to "learn more about customer's needs and behaviors in order to develop stronger relationships with them."
- CRM helps ensure that all products and services truly provide value to the customer, and that the "real" customers are being targeted and reached.
- CRM involves identifying and prioritizing customer target segments, creating customer profiles, and tailoring the communication messages and approach to their specific needs.
- The SEA Project identified five customer segments and tailored their training and presentations to the unique needs of each segment:
  - Mid-level Line Management, Project Management, SE Management, Systems Engineering Practitioners, and Process Improvement customers.
- The SEA Project also prioritized their outreach based on classes of systems.
  - **Primary**: flight and ground systems such as spacecraft, instruments, and associated ground systems.
  - **Secondary**: enterprise, business or administrative systems
  - **Excluded**: basic research and development, and advanced technology development

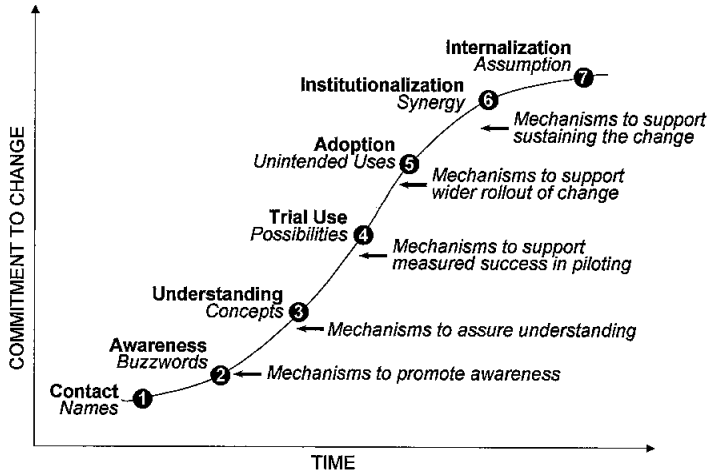
Organizational Change Management

- Organizational Change Management (OCM) is "the methodology that integrates change and the ability to adapt into the organization."
- OCM involves working with a target community to systematically introduce them to desired changes in such a way that those changes are eventually adopted and become commonplace.
  - OCM is based largely on Rogers' seminal work on diffusion of innovation. Everett M. Rogers, *Diffusion of Innovations, 5th Edition*, Free Press, 2003
  - This approach is the antithesis of "If we build it, they will come."
- The SEA Project has employed several of Rogers' strategies for optimizing the adoption of innovations:
  - Relevance, customer focus, user friendliness, education, likelihood, measurement and testimony.

Rogers' Categories of Responses to Innovation

Categories	Characteristics	Responses to Innovation
Innovators or "Techies" – those who create new technologies	Gatekeepers for any new technology; appreciate technology for its own sake; helpful critics	Will settle for buggy or difficult-to-use solution components
Early Adopters or "Visionaries" – those who are the first to try innovations	Dominated by a dream or vision; focus on business goals; usually have close ties with "techie" innovators	Can see the strategic advantage of the improvement or change and are willing to help the organization get there.
	"The Chasm" in the Adopter Continuum	
Early Majority or "Pragmatists" – those who establish an innovation's success by adopting it for regular use	Do not want to be pioneers (prudent souls); control majority of budget; want percentage improvement (incremental, measurable, predictable progress)	Can see the advantage of the improvement or change and are willing to carefully adopt it.
Late Majority or "Conservatives" – those who adopt an innovation after its success has been demonstrated	Avoid discontinuous improvement (revolution); adopt only to stay on par with the rest of the world; somewhat fearful of new technologies	Need a lot of support to adopt the solution component.
Laggards or "Skeptics" – those who never adopt or who do so reluctantly after it becomes necessary	"Nay sayers"; adopt only after technology is not recognizable as separate entity; constantly point at discrepancies between what was promised and what is	Are very resistant to changing the status quo, despite the effectiveness of the solution component.

OCM Curve and Stages



Adapted from *Out from Dependency: Thriving as an Insurgent in a Sometimes Hostile Environment*, SuZ Garcia and Chuck Myers, SEPG Conference, 2001

SEA Use of OCM at JPL

OCM Stages	OCM Stage Name	OCM Definition at JPL	Associated OCM Activities
0	None	Never heard of SEA Project	None
1	Contact	Have heard of SEA Project	SEA publicity and outreach activities -- SEA brochure, bookmark, announcements, e-mail, fliers, posters, etc.
2	Awareness	Aware of SE standards, practices and procedures, and existence of SEA Seminar Series, SEA website, SEA Road Show, and model-based design concepts	SEA Target Audience list and SE disciplines, SEA website, SEA Seminar Series, SEA "Road Show", BEACON SE Online Guide, user forums, surveys, SE procedures and Flight Project Practices in JPL Rules!, MBED Overview/Tutorial
3	Understanding	Understand SE practices and procedures, model-based design concepts, basic SEA products (templates,), SE competencies	Systems Engineering at JPL course, SEA training courses, SE Discipline training, SEA Seminar Series, SEA "Lunch and Learn" Series, SEA function masters
4	Installation (Trial Use)	Utilize SE practices and procedures, model-based design tools, and some SEA products and services	SEA consulting – planning, SE practices and procedures, , tools, etc.; benefits & rationale, case studies, SEA impact metrics, SEA OJT internships, model-based design tools
5	Adoption	Some orgs/projects comply with institutional policies and practices (SE practices and procedures); use model-based design tools; apply SE competencies to hiring, annual evaluations (ECAPs) and SE career management	SE target sections, SEA consulting support, more training/coaching, lessons learned; address barriers to change; SE career paths & development plans, SE Competencies List, Fellow-level SE recruiting, ESD model-based design framework
6	Institutionalization	All orgs and projects performing SE comply with institutional policies and practices (SE practices and procedures); use model-based design tools; apply SE competencies to hiring, annual evaluations (ECAPs) and SE career management	SEA Element activities in concert with ESD line orgs, SEA OCM activities and metrics; SE career paths & development plans, SE competency model and valued behaviors, ESD model-based design Center and consulting support
7	Internalization	Institutional policies and practices (SE practices and procedures) inculcated into ESD line organizations.	Appraisals or assessments, continuous process improvement, comprehensive training program, annual institutional performance appraisal of line managers that appropriately rewards and reinforces desired behavior

Lessons Learned

(as time permits)

Lessons Learned -- Process Improvement

1. Build on previous efforts. The SEA Project was able to build on previous reengineering efforts
   - Process-Based Management (PBM) and ISO 9000 in the late 1990's.
   - Software Quality Improvement (SQI) Project in the mid 2000s.
2. Take the time to survey your stakeholders and identify their "care abouts."
   - Understanding what your stakeholders care about gives legitimacy to your effort and ensures that you focus on the things that are "wildly important" to them.
3. Address all three aspects of change management: people, process and technology.
   - It's tempting to just focus on generating processes or on exploring fascinating technology and ignore or minimize the people component.
   - Systems engineering is a people intensive activity, and the behaviors and training needs of systems engineers must be addressed to truly have an impact on the culture.
4. Reach the "front line" and middle managers too.
   - Senior management support is important, however, so is the support of "front line" managers and middle managers.
   - That support needs to be painstakingly earned, one meeting or presentation at a time.
5. Other concurrent major changes can be a mixed blessing, i.e., sources of distraction or opportunity.
   - Recent major reorganization of the entire Engineering and Science Directorate (ESD) at JPL
   - Recent JPL downsizing.

Lessons Learned -- Creating Assets

6. Start by defining the basic systems engineering processes.
   - Defining these processes is a necessary step to ensure that a robust process is available and ready to be utilized.
7. Evaluate and select tools to support the design process.
   - When you do the ground work of evaluating model-based systems engineering tools and setting up a framework for their use, then users are much more likely to try them and view them as "user friendly."
8. Utilize many reviewers to promote ownership.
   - When many reviewers who are representative of different domains and perspectives provide comments on new or revised products, it promotes ownership or "buy-in" of the final result.
9. Allocate sufficient time for curriculum development.
   - Curriculum development and defining course content is very time consuming.
   - On average, it takes approximately four months to develop a new course.

Lessons Learned -- Deploying Assets

10. Use OCM and CRM to facilitate change. Advantages include:
    - It helps to maintain a customer focus and to create motivation for reaching out to customers.
    - When setting priorities, it helps to know who is your primary audience vs. your secondary audience.
11. Address "culture issues" head on when deploying assets.
    - The major paradigm shift involved in using model-based engineering design (MBED) tools.
    - Factors that engendered resistance to change, such as the perception of insufficient time and resources to try something new, program and project constraints, and the difficulty of change itself.
    - "Baggage" from previous process improvement efforts and the false perception of "just another unfunded mandate."
12. Conduct surveys and measure regularly.
    - Conduct regular surveys and user forums to determine the level of infusion into the organization and to uncover any barriers to acceptance.
    - Measure infusion, effectiveness, customer satisfaction, progress, etc. Remember that "without measurement, you're just guessing!"
13. Communicate via multiple avenues and promote shamelessly.
    - No matter how many times a message is communicated, there still may be some who haven't gotten the message.
    - Some people prefer e-mail, while others prefer fliers, posters, presentations or seminars.
    - It helps to think of novel ways to attract attention such as bookmarks, cubicle pins, brochures, websites, etc.

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Track 14 Session 14.01

Developing the Systems Engineering Workforce at JPL

March 8, 2006

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  - SEA Seminar Series
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  - Organizational Change Management

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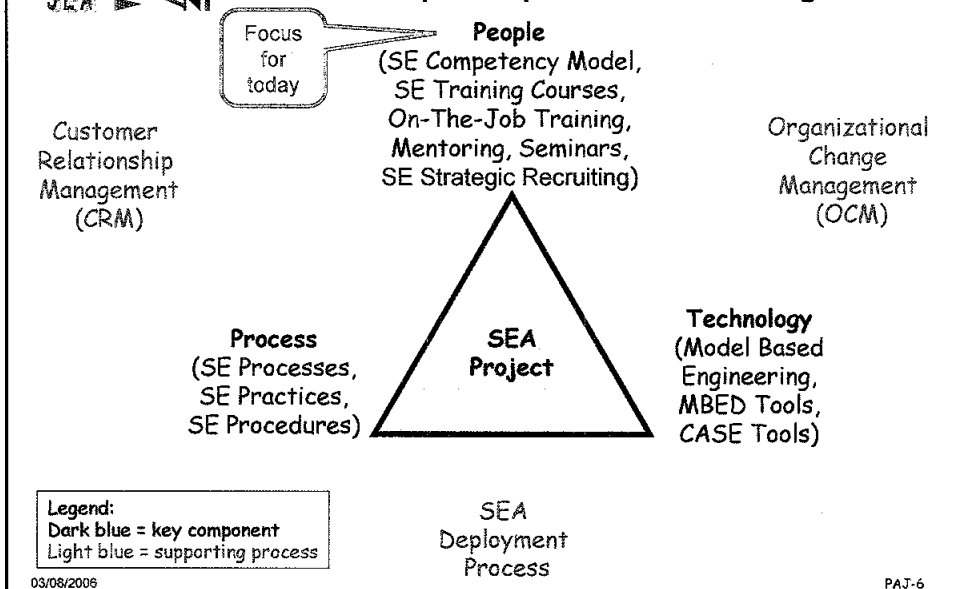

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Systems Engineer Competency Model

This model will be used to:
- Screen candidates for external hire
- Conduct internal assessments
- Drive training content
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Technical Knowledge

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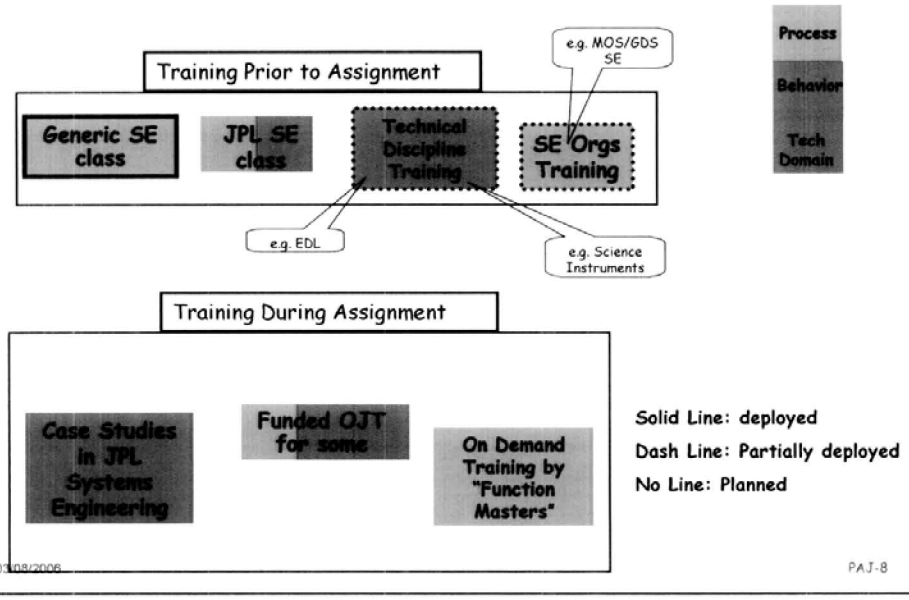
Elements of SE Training



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SEA On-The-Job Training (OJT) Program

JPL

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Key Findings and Implications

JPL

- **Key Findings:** All three components of change management must be addressed – people, process and technology – and the people component is where the maximum leverage is gained.
  - Knowing how successful systems engineers behave and sharing that information with the SE community establishes a standard for hiring, evaluation and personnel development.
- **Implications:** Orgs. need to focus on more than the technical aspects of the job of systems engineering.
  - They need to identify and employ creative ways of identifying and training future SEs, and then inculcate successful personal behaviors and leadership skills.

Backup Slides

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  - An approach not usually invoked in an engineering environment.
- CRM is a strategy used to "learn more about customer's needs and behaviors in order to develop stronger relationships with them."
- CRM helps ensure that all products and services truly provide value to the customer, and that the "real" customers are being targeted and reached.
- CRM involves identifying and prioritizing customer target segments, creating customer profiles, and tailoring the communication messages and approach to their specific needs.
- The SEA Project identified five customer segments and tailored their training and presentations to the unique needs of each segment:
  - Mid-level Line Management, Project Management, SE Management, Systems Engineering Practitioners, and Process Improvement customers.
- The SEA Project also prioritized their outreach based on classes of systems.
  - **Primary**: flight and ground systems such as spacecraft, instruments, and associated ground systems.
  - **Secondary**: enterprise, business or administrative systems
  - **Excluded:** basic research and development, and advanced technology development

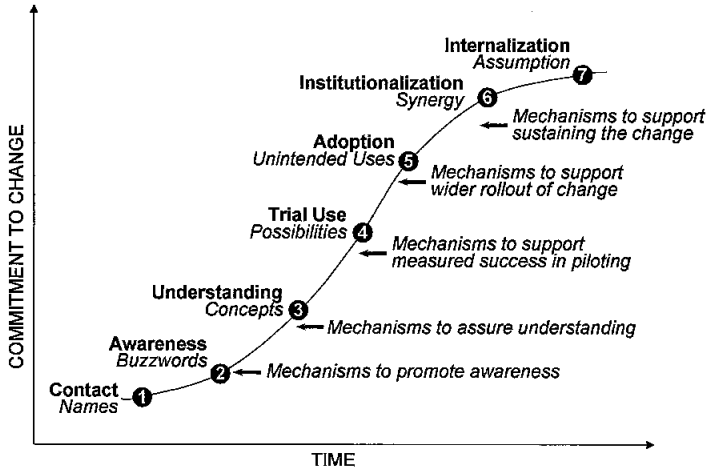
Organizational Change Management

- Organizational Change Management (OCM) is "the methodology that integrates change and the ability to adapt into the organization."
- OCM involves working with a target community to systematically introduce them to desired changes in such a way that those changes are eventually adopted and become commonplace.
  - OCM is based largely on Rogers' seminal work on diffusion of innovation. Everett M. Rogers, *Diffusion of Innovations, 5th Edition*, Free Press, 2003
  - This approach is the antithesis of "If we build it, they will come."
- The SEA Project has employed several of Rogers' strategies for optimizing the adoption of innovations:
  - Relevance, customer focus, user friendliness, education, likelihood, measurement and testimony.

Rogers' Categories of Responses to Innovation

Categories	Characteristics	Responses to Innovation
Innovators or "Techies" – those who create new technologies	Gatekeepers for any new technology; appreciate technology for its own sake; helpful critics	Will settle for buggy or difficult-to-use solution components
Early Adopters or "Visionaries" – those who are the first to try innovations	Dominated by a dream or vision; focus on business goals; usually have close ties with "techie" innovators	Can see the strategic advantage of the improvement or change and are willing to help the organization get there.
	"The Chasm" in the Adopter Continuum	
Early Majority or "Pragmatists" – those who establish an innovation's success by adopting it for regular use	Do not want to be pioneers (prudent souls); control majority of budget; want percentage improvement (incremental, measurable, predictable progress)	Can see the advantage of the improvement or change and are willing to carefully adopt it.
Late Majority or "Conservatives" – those who adopt an innovation after its success has been demonstrated	Avoid discontinuous improvement (revolution); adopt only to stay on par with the rest of the world; somewhat fearful of new technologies	Need a lot of support to adopt the solution component.
Laggards or "Skeptics" – those who never adopt or who do so reluctantly after it becomes necessary	"Nay sayers"; adopt only after technology is not recognizable as separate entity; constantly point at discrepancies between what was promised and what is	Are very resistant to changing the status quo, despite the effectiveness of the solution component.

OCM Curve and Stages



Adapted from *Out from Dependency: Thriving as an Insurgent in a Sometimes Hostile Environment*, SuZ Garcia and Chuck Myers, SEPG Conference, 2001