Systems Engineering Standards: A Summary

1.0 Systems Engineering Standards and Models

Several Systems Engineering process standards and models exist that describe so-called Systems Engineering processes as well as “best practices” in accomplishing Systems Engineering. Past and current process standards and models include:

- MIL-STD-499 Series
- ANSI/EIA 632
- IEEE 1220
- ISO/IEC 15288
- CMMI

1.1 MIL-STD 499 Series. These military standards had a profound impact on the early development of Systems Engineering and standardization of its processes. The series started in 1969 when the US Air Force published MIL-STD-499 which was updated and republished in 1974 as MIL-STD-499A. Entitled “Engineering Management”, the stated objective of it was “…to assist Government and contractor personnel in defining the Systems Engineering effort in support of defense programs.” The Systems Engineering process model included: (1) Mission Requirements Analysis; (2) Functional Analysis; (3) Allocation and (4) Synthesis. See Figure 1.

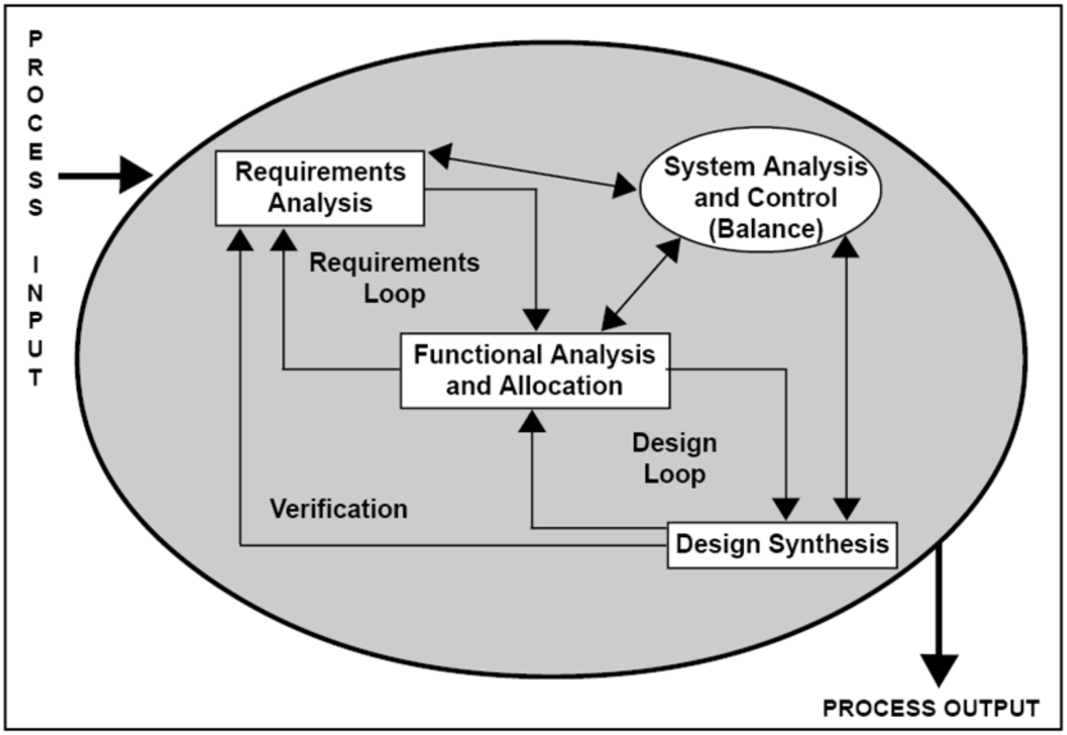

Figure 1: Example of a Systems Engineering Process Model

MIL-STD 499A was expanded and updated as the draft MIL-STD-499B ("Systems Engineering"). However, it was never formally published. As part of the 1990's Acquisition Reform movement which cancelled or replaced nearly all DoD-unique military specifications, MIL-STD-499B was withdrawn. An interim industry standard (EIA/IS-632), which was a "commercialized" version of the May 1994 version of MIL-STD-499B was published in December 1994.

1.2 ANSI/EIA 632. This standard originally published as an interim standard (IS) in 1994[1] which closely mirrored MIL-STD-499B, was significantly revised, made more abstract and general and re-published in January 1999. Titled "Processes for Engineering a System", EIA 632's stated purpose is: "…provide an integrated set of fundamental processes to aid a developer in the engineering or re-engineering of a system."

EIA 632 limits the set of required processes to those directly related to the technical aspects of engineering systems (13 processes included) and provides 33 requirements associated with completing the processes. It defines representative tasks and the expected outcomes associated with each one. There is not one process but a series of processes, in groups, with loops among them. See Figure 2.

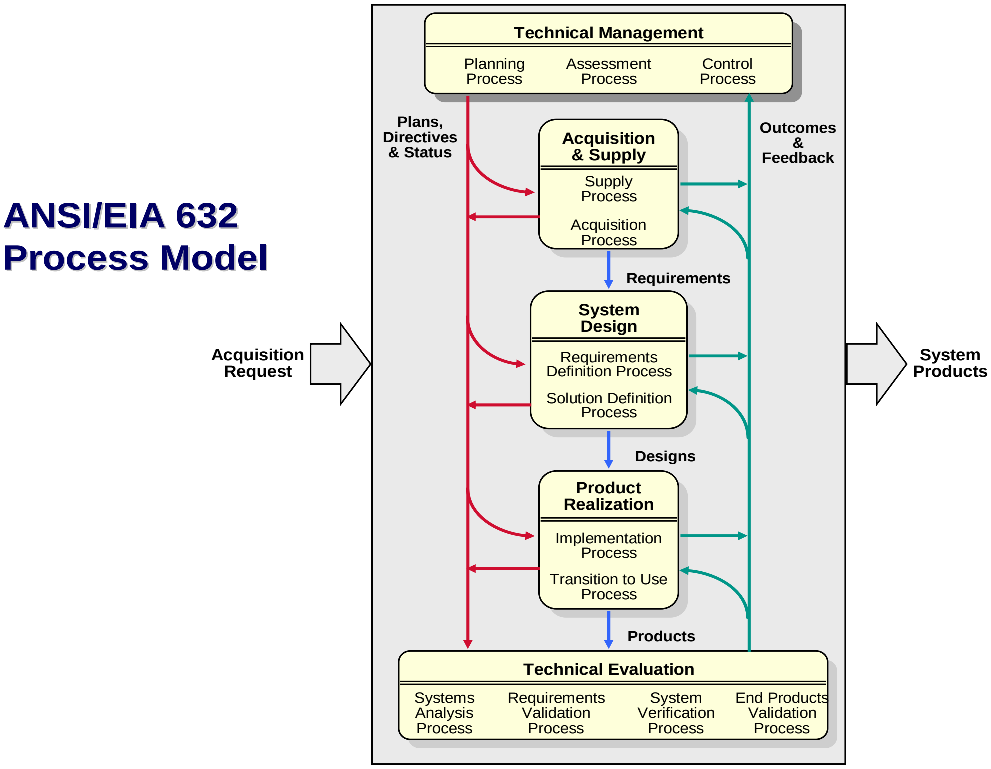

Figure 2: ANSI/EIA 632 Process Model

[1] Many definitions of Systems Engineering exist. The DoD's definition, as specified in the Defense Acquisition Guidebook, is derived partially from EIA/IS 632. That defines Systems Engineering as: "An interdisciplinary approach encompassing the entire technical effort to evolve and verify an integrated and total life-cycle balanced set of system, people, and process solutions that satisfy customer needs".

One key concept in EIA 632 is that of a system model oriented around “Building Blocks”. Each Building Block is a system in itself, and thus consists of the End Products (which are defined by a customer need and perform the operational functions required by a customer), plus products and processes called Enabling Products that are necessary to develop, realize, test, deploy, utilize, support, and retire those products.

1.3 IEEE 1220. This standard, entitled “Application and Management of the Systems Engineering” provides the next-level-of-detail description of the systems engineering processes defined in EIA 632. IEEE 1220 was originally published in 1995 as a trial-use standard; based on experience with the standard it was revised and published as a full standard in 1998. The stated purpose of IEEE 1220 is “...to provide a standard for managing a system from initial concept through development, operations and disposal”.

IEEE 1220 defines a Systems Engineering Process as a “generic problem-solving process, which provides the mechanisms for identifying and evolving the product and process definitions of a system.” The Systems Engineering Lifecycle Model consists of: (1) System definition; (2) Subsystem definition (i.e., preliminary design, detailed design, fabrication/assembly/integration and test); and (3) Production and customer support.

The Systems Engineering Process model outlined in IEEE 1220 conceptually is very similar to that of Figure 1 and includes: (1) Requirements Analysis; (2) Requirements Validation; (3) Functional Analysis; (4) Functional Verification; (5) Synthesis; and (6) Physical Verification. These processes are linked together via Control Processes consisting of Data Management; Configuration Management; Interface Management; Risk Management and Performance-based Progress Measurements. See Figure 3.

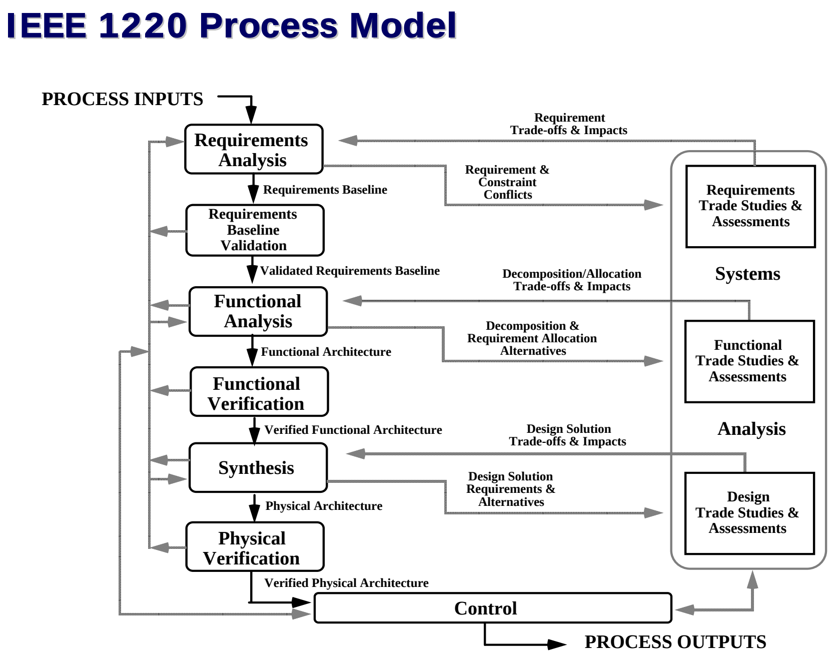
IEEE 1220 Process Model
PROCESS INPUTS
Requirements Analysis
Requirement Trade-offs & Impacts
Requirement & Constraint Conflicts
Requirements Baseline
Requirements Baseline Validation
Requirements Trade Studies & Assessments
Validated Requirements Baseline
Decomposition/Allocation Trade-offs & Impacts
Systems
Functional Analysis
Decomposition & Requirement Allocation Alternatives
Functional Architecture
Functional Trade Studies & Assessments
Functional Verification
Verified Functional Architecture
Design Solution Trade-offs & Impacts
Analysis
Synthesis
Design Solution Requirements & Alternatives
Physical Architecture
Design Trade Studies & Assessments
Physical Verification
Verified Physical Architecture
Control
PROCESS OUTPUTS

Figure 3: IEEE 1220 Systems Engineering Process

1.4 ISO/IEC 15288: 2002[2]. This standard, now retired, entitled “Systems Engineering--System Life Cycle Processes”, has an extremely broad scope. It applies “…to the full life cycle of systems, including conception, development, production, utilization, support and retirements of system and to [their] acquisition and supply.”

The processes specified in ISO/IEC 15288 cover the entire acquisition, program management and technical development gamut and establish “a common framework from describing the lifecycle of systems created by humans.” See Figure 4.

Systems, similar to EIA 632, are conceived to consist of two parts: (1) the system-of-interest (in EIA 632, the End Product) that provides desired capabilities and services and (2) Enabling systems (EIA 632 uses the same terminology) that provide required services in each system lifecycle stage to include concept, development, production, utilization, support and retirement.

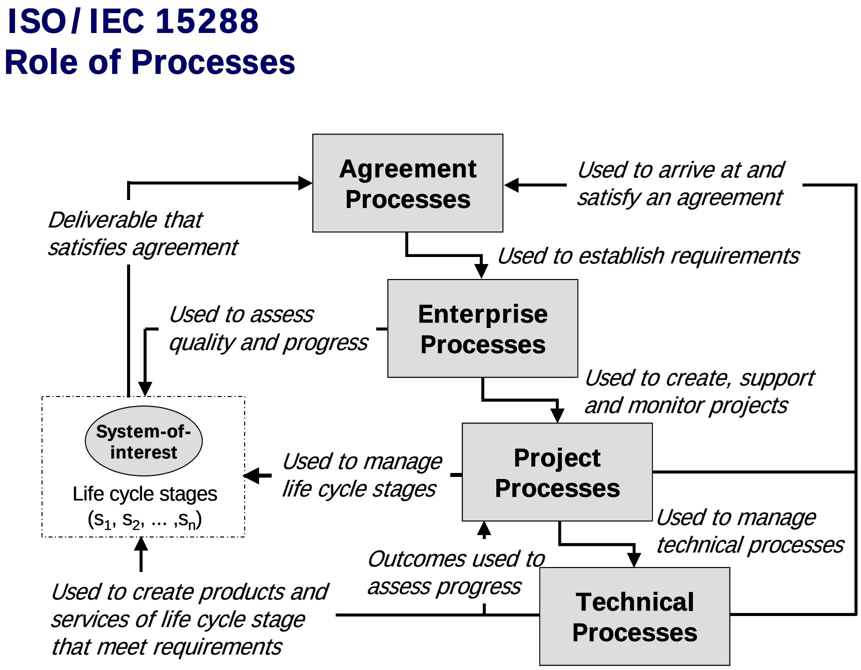
ISO/ IEC 15288
Role of Processes
Agreement Processes
Used to arrive at and satisfy an agreement
Deliverable that satisfies agreement
Used to establish requirements
Enterprise Processes
Used to assess quality and progress
Used to create, support and monitor projects
System-of-interest
Life cycle stages
(s_1, s_2, … ,s_n)
Used to manage life cycle stages
Project Processes
Used to manage technical processes
Outcomes used to assess progress
Used to create products and services of life cycle stage that meet requirements
Technical Processes

Figure 4: The Role of Processes in ISO/IEC 15288:2002

Life cycle processes as specified in ISO/IEC 15288 include:

- **Agreement Processes:** covering acquisition and supply of systems
- **Enterprise Processes:** describing resources and infrastructure necessary to support projects and ensure satisfaction of organizational objectives.

[2] Note: ISO 15288:2002 was replaced by ISO 15288:2008 that was published in January 2008. A summary of ISO 15288:2008 is provided in the next paragraph. However, because during this transition period, uses of both standards may be encountered in practice, the ISO 15288:2002 discussion is still retained in this document for reference purposes.

- **Project Processes:** which are used to establish and evolve project plans; to assess actual achievement and to control project execution. These include such processes as Decision-Making, Risk Management, Configuration management, Information/Data Management and Assessment.
- **Technical Processes**: these are those used to define requirements; to transform them into an effective product; to reproduce/produce the product; to effectively use, sustain and dispose of the product.

Each of these processes are further broken down into subsidiary processes. They are illustrated in Figure 5 below. The DoD's eight System Engineering Technical Processes[3] are a subset of the Technical Processes derived from ISO 15288:2002.

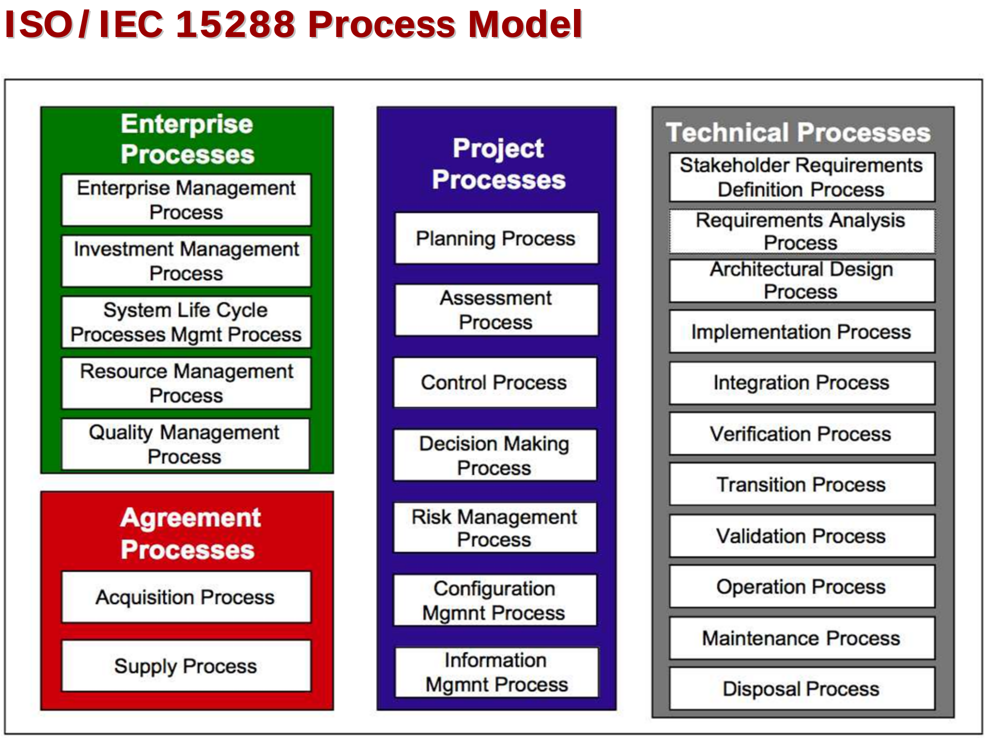

Figure 5: ISO/IEC 15288:2002 Process Details

[3] These processes are: Stakeholder Requirements Definition, Requirements Analysis, Architectural Design, Implementation, Integration, Verification, Validation and Transition.

1.5 ISO/IEC 15288:2008 This standard, entitled “Systems Engineering--System Life Cycle Processes”, replaced ISO 15288:2002 in January 2008. Like its predecessor, it has an extremely broad scope. It “…establishes a common process framework for describing the life cycle of man-made systems…[describing] a set of processes and associated terminology for the full life cycle including conception, development, production, utilization, support and retirement and also supports the definition, control assessment and improvement of these processes”.

Systems Engineering standards and software development standards historically have not been well aligned. Different process names and procedures were used, making the interface between software and system development confusing at best. One of the goals in development of ISO/IEC 15288:2008 was to initiate a harmonization effort between it and the corresponding ISO/IEC 12207:2008 (Systems Engineering--Software Life Cycle Processes) both at the international and national levels. To that end, the IEEE has adopted ISO/IEC 15288:2008 as a US national standard, numbering it as IEEE Std 15288™-2008. Additionally, the corresponding international software standard was updated as ISO/IEC 12207:2008, adopted by the IEEE and published as IEEE Std 12207™-2008.

Many processes in ISO/IEC 15288: 2008 are similar to those in its 2002 predecessor, with some refinements to better align systems and software development processes. See Fig 6 below.

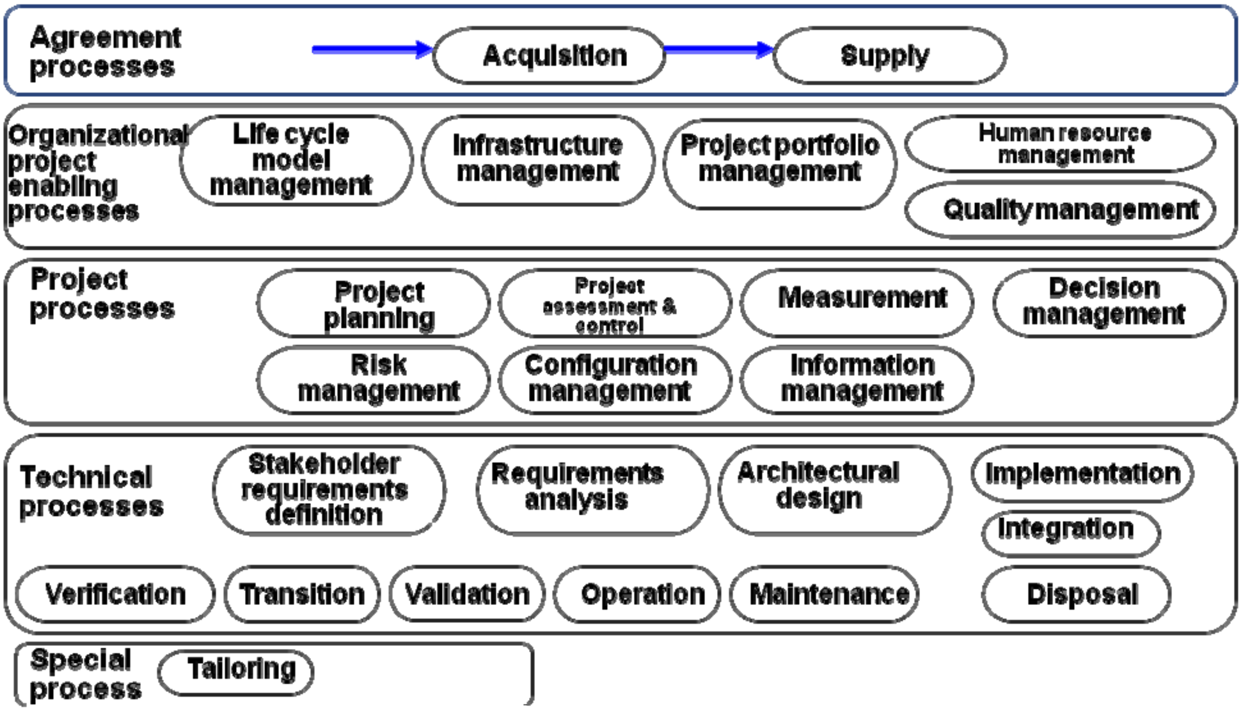

Figure 6 ISO 15288:2008 Process Sets

1.6 CMMI. The Capability Maturity Model, Integrated or CMMI refers to a product suite of development, acquisition and service processes models[4] designed to be used for process improvement. It can be used to assess, from an organizational perspective, how well the organization's standard processes are being performed and provide recommendations on how the processes can be improved. The CMMI breaks processes down into Categories and Process Areas.

Categories of processes included in the CMMI-DEV model include Process Management, Project Management, Engineering and Support. Each of these categories in turn is broken down into a number of Process Areas (PAs) for each category.

The CMMI can be used in two ways: (1) as a "staged model" in which the PAs are assessed and a "level" rating score is assigned to an organization; or (2) as a "continuous" model which provides a range of scores for each Process Area. See Figure 7.

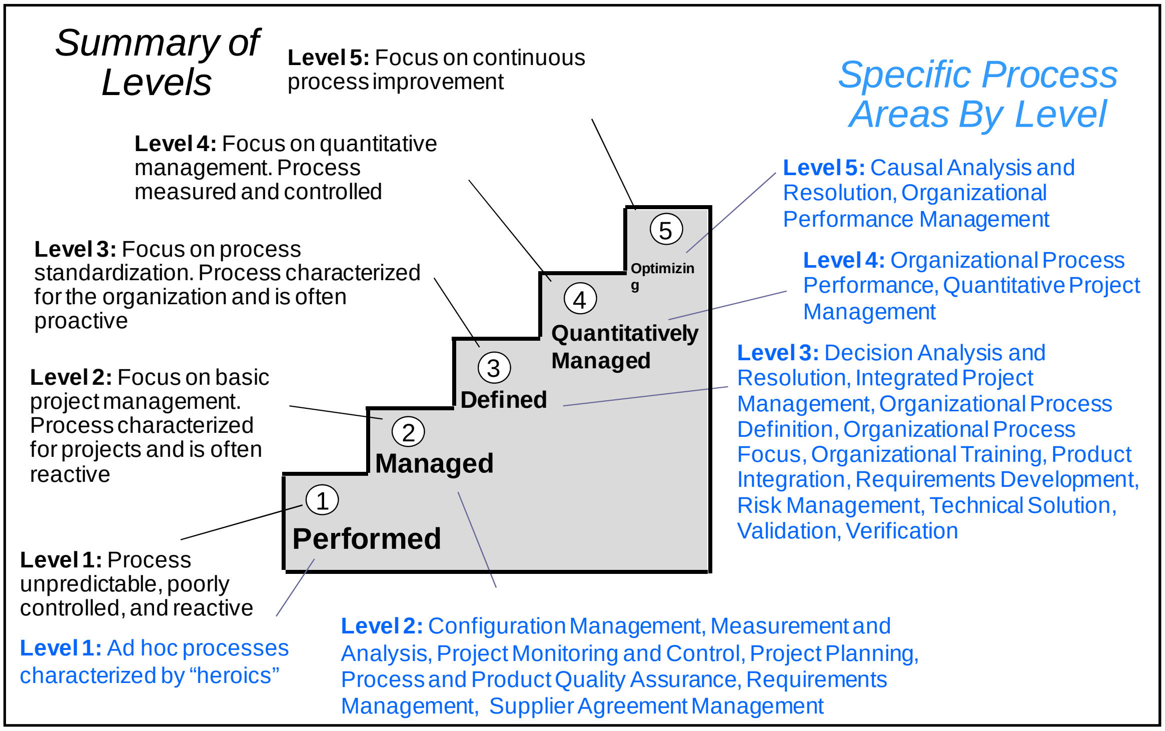
Summary of Levels
Level 5: Focus on continuous process improvement
Level 4: Focus on quantitative management. Process measured and controlled
Level 3: Focus on process standardization. Process characterized for the organization and is often proactive
Level 2: Focus on basic project management. Process characterized for projects and is often reactive
Level 1: Process unpredictable, poorly controlled, and reactive
Level 1: Ad hoc processes characterized by "heroics"
1
Performed
2
Managed
3
Defined
4
Quantitatively Managed
5
Optimizin g
Specific Process Areas By Level
Level 5: Causal Analysis and Resolution, Organizational Performance Management
Level 4: Organizational Process Performance, Quantitative Project Management
Level 3: Decision Analysis and Resolution, Integrated Project Management, Organizational Process Definition, Organizational Process Focus, Organizational Training, Product Integration, Requirements Development, Risk Management, Technical Solution, Validation, Verification
Level 2: Configuration Management, Measurement and Analysis, Project Monitoring and Control, Project Planning, Process and Product Quality Assurance, Requirements Management, Supplier Agreement Management

Figure 7. CMMI-DEV, version 1.3

[4] These models are part of the CMMI "constellation" which includes the CMMI for Development (CMMI-DEV), the CMMI for Acquisition (CMMI-ACQ) and the CMMI for Services (CMMI-SVC). They all share common core processes with tailored processes added that are suitable for each the three cited domains.

2.0 Levels of Application

The Systems Engineering standards discuss above differ primarily in their depth and breadth of coverage.

- **ISO/IEC 15288:** has the greatest breadth but the least depth of coverage. This standard is designed to be used by an organization, a project within an organization, or an acquirer and a supplier via an appropriate agreement. ISO 15288 has been revised in early 2008 to as part of a harmonization effort to align Systems Engineering and Software Engineering processes, and a variety of companion implementing handbooks are in revision by the ISO organization.

- **EIA 632:** defines the set of requirements for engineering a system. The processes in EIA 632 describe ‘what to do’ with respect to the processes for engineering a system. These are at the next level down from the ISO/IEC 15288 level of system life cycle processes.

- **IEEE 1220:** defines a Systems Engineering process. It gives the next level of detail below the process requirements described in EIA 632. The process is described more at the task or application level.

- **IEEE 15288:2008**: a US standard, is identical to the ISO/IEC 15288 2008 edition.

IEEE 1220 has the greatest depth of coverage for its limited scope but the least breadth. EIA-632 falls between the other two. See Figure 8.

It is not necessarily a question of choosing just one standard for a program. Depending on the specific needs of a given program, all three may be employed.

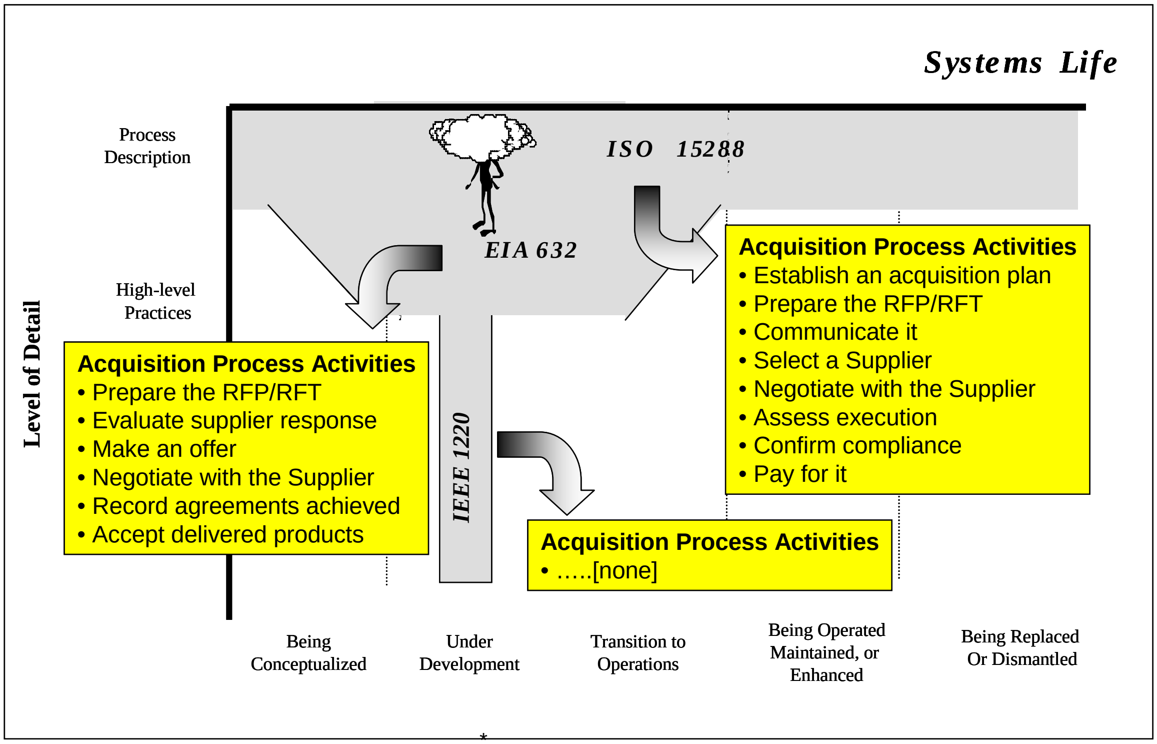
Systems Life
Process Description
High-level Practices
Level of Detail
ISO 15288
EIA 632
IEEE 1220
Acquisition Process Activities
• Prepare the RFP/RFT
• Evaluate supplier response
• Make an offer
• Negotiate with the Supplier
• Record agreements achieved
• Accept delivered products
Acquisition Process Activities
• Establish an acquisition plan
• Prepare the RFP/RFT
• Communicate it
• Select a Supplier
• Negotiate with the Supplier
• Assess execution
• Confirm compliance
• Pay for it
Acquisition Process Activities
• …..[none]
Being Conceptualized
Under Development
Transition to Operations
Being Operated Maintained, or Enhanced
Being Replaced Or Dismantled

Figure 8 Scope of SE Standards (after Doran, SPC IEEE 1220/SC7 WG7 SE Study Group Report