# CONDUCT SYSTEM INTEGRATION

Version 6.2
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# CONDUCT SYSTEM INTEGRATION

## 1. DESCRIPTION

**T**he Systems Integration Process (SIP) includes all actions taken to define System Integration, quantify System Integration, and to define approaches to Sub-processes of System Integration, such that the SIP can be understood by an engineer new-hire.

Identification of process addresses System Integration categories. Included are all approaches to System Integration associated with any of three System Integration categories.

- Integration with Other Systems: External System Integration
- Integration of the System being developed: [Internal] System Integration
- Integration of the System being developed with operational supportability requirements

Thus, this process includes the sub-process of balancing the System Integration levels between these three System Integration categories. Functional system Integration begins in the design phase and is a continuous process that results in fabrication of the end-items, such that they interface as specified in Hardware and Software Configuration Items (HWCI/SWCI) Physical system integration begins with fabrication and assembly, and ends with test. IEEE P1220 System Engineering standard treats FAIT as a continuous process. Physical integration/interface (form/fit/function) addresses interpretability with internal and external systems.

SIP is an essential part of the system engineering process (SEP); by some definitions the two are one and the same; In the view of (eco)system process, one inevitably leads to the other. There is consensus in the literature/by the experts, that the measure of integrated system performance is system effectiveness. (See Definitions, Section 19)

The relation to the system engineering management process (SEMP), is that the SEMP leads to both SEP/SIP, thus making the measure of outcome of system engineering and integration a measure of SEMP. The ultimate measure of all, is system effectiveness and cost/effectiveness.

Within the scope of the literature search conducted, a robust definition of “System Integration” was hard to find. Thus development and documentation of the SIP requires some interpretation of applicable references and bibliography, in which “integrate” and/or “integration” appears, either straight-forwardly or by inductive or deductive logic. The latter requires that SIP be voted on by a write-in ballot. For that reason, commentary is included in the references & bibliography section at the end of this document.

A summary Template is provided in Figure 1. A SIP Flow Diagram in provided in Figure 2. The overall SEP that includes SIP is mapped by the flow diagram in figure 3.

This Draft, complete for 12 Sept 95 review purposes, needs some administrative tweaking and additional research/comments for next review.

## Conduct System Integration

### Preceding Process
Design /ICD's/CDR Complete
Fab, Assembly, Test of Sys Components complete

### Next Process
Verification & Validation

### Purpose
Ensure Interoperability/interface with external world and system internal interface, per user needs.

### Critical
Form, fit & function with External/Internal Systems

### Inputs [Suppliers]
MSN/ORD [PM/User]
Acq Program Baseline [PM]
SEMP {APM(S&E)SEM/4.1]
SEIP [SE 4.1.1/4.1.2]*
SI Plan [4.1.2]*
M&S [4.1.3/4.10]
HWICD's/SWICD's [SE]*

*Prime Contractor is normally responsible for SIP, govt for [reduced] oversight.

### Primary sub-processes
System Integration Planning
SI Facilities &Tools Resouring
Fabrication, Assembly & Test
Demonstrations/Tests
Demo/Tests Reporting and Review

### Outputs [Customers]
IntegratedSystem [APM(S&E)]
Integrated Design Assessment Report [APM(S&E)]
DT&E Verifcation Report [PM, APM(S&E)]
DT/OT Transistion Report [PM, APM(S&E), OPTEVFOR]

### Entry Criteria
Detailed Design Complete
Fab, Assemble, Integrate, Test complete below level three: (FAIT at or below Subsystem Level Complete)

### Supporting sub-processes
Development of ORD<=>System Requirements
Development of HW/SW ICD's
Readiness and Design Reviews

### Exit Criteria
Test/Demo Complete
Test Readiness Review Passed
(V&V Preparation)

### Agents
Program Management (1.0)
APM(S&E) (4.1/4.1.1)
SE- Sys Dev & I (4.1.2)
SE- M&S (4.1.3/4.10)

### Tools
Assembly Tools
SI Unique Test Equipment
System Performance M&S
System Effectiveness Database

### Handbooks, Standards, Limits
System Engineering Standards (Commercial/ Military)
Commercial: IEEE P1220; EIA-632; IEEE 1498
Military: MIL-STD-498; MIL-STD-721 (RAM def); Ao Handbook (OPNAVINST 3000.12)
System Engineering Handbook (DSMC)

### Metrics and Measures
System Effectiveness Metrics and Measures
+ Operational Availability (Ao)
+ Operational Reliability (Ro)
+ Operational Capability (Co)/Process Capability (Cp)
+ System Reliability & Maintainability (R&M)

**FIGURE 2. SYSTEMS INTEGRATION FLOW CHART**

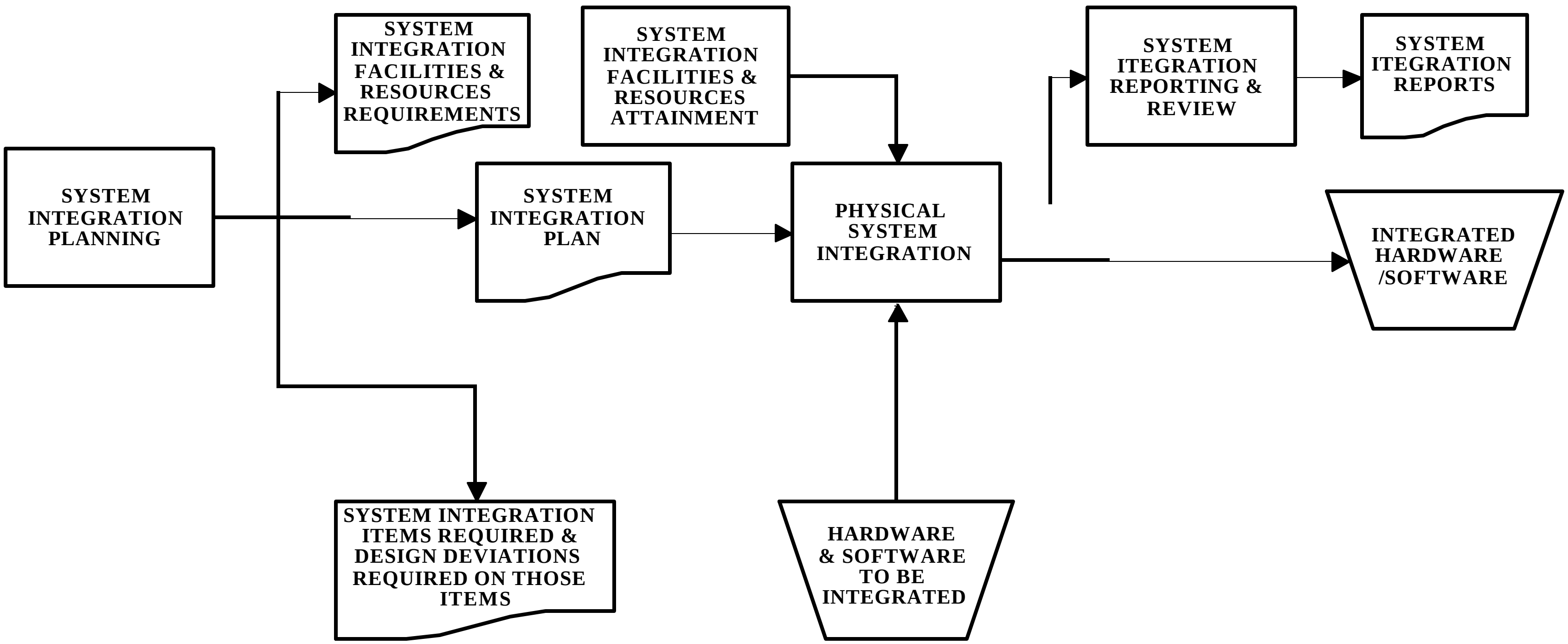


**FIGURE 3. SYSTEM ENGINEERING DEVELOPMENT FLOW CHART**

## 2. PURPOSE (CRITICAL)

The purpose of the system integration process is to ensure system form, fit, and functionality, commonality and interoperability of:

+ Sub-systems that constitute, or support the System under development, including support systems.

+ The System under development, in relation to external Systems with which it must interface in the operational environment. The external integration for system interface is especially important due to joint service interoperability requirements.

The System Integration process is critical because it provides Program Management/Systems Engineering Management the information required for them to address potential system interface problems areas before they become real problems, early in the design phase.

Controlling the SIP is critical to controlling integrated system performance that meets the needs of the customer.

## 3. PROCESS OWNER

The NAWC owner of the System Integration Process (SIP) is Systems Development and Integration competency [4.1.2]

## 4. PRIMARY SUB-PROCESSES

Because System integration is a virtually all-encompassing continuous process, from Milestone 0 onward, starting from the design trade-offs in the concept stage, and continuing through fabrication and verification/validation in DT/OT/IOC, there are a variety of related processes that support the system integration process.

Design Integration Process is addressed more directly in another process document. Its relation to physical fabrication

To fully appreciate the process, one must consider System Integration in context of the continuous evolution of Fabricate, Assemble, Integrate and Test (FAIT).

The Prime Contractor is normally responsible for system integration. Component parts and assemblies are fabricated and delivered to assembly points. Physical System Integration thus proceeds in a progressive manner until subsystems are fully integrated into a system. The government normally becomes involved at the subsystem level.

The subprocesses are:

**SYSTEM INTEGRATION PLANNING PROCESS**

Development of system engineering management plan
Development of system engineering implementation plan
Development of system integration plan

**SYSTEM INTEGRATION FACILITIES & RESOURCES ATTAINMENT**

Hardware In Loop Evaluation Facilities
Software Evaluation Facilities
Modeling and Simulation Facilities
Special Check-out/QA Facilities
Ground Support Equipment Interface Facilities

**PHYSICAL SYSTEM INTEGRATION PROCESS**

Assembly of Subsystems and Integration into a total System
Assembly of Subsystem Components and Integration of Subsystem

**SYSTEM INTEGRATION VERIFICATION PROCESS**

Contractor Demonstration and Test Phase
Developmental Testing and Evaluation (Verification/ some Validation

**SYSTEM INTEGRATION REPORTING & REVIEW PROCESS**

Contractor DEMONSTRATION Process and Reporting
Development of Integrated Design Assessment Report (IDAR Per S&E Inst 5451.2)
Development of system integration report in DT/OT transition Report (Per NAWCAD FTEG Report Writing Guide, Mar 94, P. RWG.9-10)

## 5. SUPPORTING SUB-PROCESSES (see figure 2)

Because System integration is a virtually all-encompassing continuous process, starting from the design trade-offs in the concept stage, and continuing through fabrication and verification/validation in DT/OT/IOC, there are a variety of subprocesses that support the system integration process.

**DESIGN STAGE**

Concurrent Development of ORD - System Requirements thru COEA Process, or similar process.

Development of Interface Control Documents
Readiness and Design Reviews

**FABRICATION STAGE**

Product Baseline Development

## 6. INPUTS & SUPPLIERS

### INPUTS

**User**

Deficiency Reports
Mission Need Statement (MNS)
Operational Requirements Document (ORD)
Concept of Operations

**Program Management**

Acquisition Program Baseline (APB)
Program Master Plan (PMP)
System Requirements

**Systems Engineering**

Systems Engineering Management Plan (SEMP)
System Engineering Implementation Plan (SEIP)
System Integration Plan (SIP)
Interface Control Documents (ICD's)
- Hardware ICD's
- Software ICD's
Test and Evaluation Master Plan (TEMP)
System Concept
Service Use Profile
Type/Performance Specification
System Technical Performance Requirements

### PRIME SYSTEM INTEGRATION SUPPLIER

The system integration supplier is normally the prime contractor.

## 7. PRECEDING PROCESSES

Because Integration through Design and Development is a necessary prerequisite, for integration that considers form, fit and function, with external and internal interfaces, the discussion of preceding processes starts here.

**DESIGN**

EXTERNAL DESIGN INTEGRATION:

Mission Need Statement (MNS)
Operational Requirements Document (ORD)
DEVELOP SYSTEM REQUIREMENTS
(Interface Definition and Control Documents to EXTERNAL WORLD)

INTERNAL DESIGN INTEGRATION:

Mission Need Statement (MNS)
Operational Requirements Document (ORD)
DEVELOP INTERNAL SYSTEM DESIGN by functional analysis
+ Operational Requirements Allocation
+ Functional Requirements Allocation
+ HW/SW Interface Control Documents (ICD's)

**FABRICATION**

Develop Detailed Design (Decomposition and Synthesis)
Conduct Critical Design Review
Delivery of Completed:
+ Sub-Assemblies
+ Assemblies
+ subsystems

## 8. ENTRY CRITERIA

Entry criteria for entering the Fabricate, Assemble, Integrate & Test (FAIT) is subsystem stage of integration complete progressing to system integration. This is preceded by progressive FAIT of Sub-Assemblies, Assemblies, subsystems, etc.

**Required to Start**
Certification that Contractor has passed Critical Design Review (APM(S&E)
Funding for Level of Production.

**Will Cause to Start**

Initiation by Program Management
Funding by Contracting Officer
Meeting of criteria set in System Engineering Management Plan

## 9. NEXT PROCESS

### TEST PREPARATION/TEST READINESS REVIEW

In the paradigm of Fabricate, Assemble, Integrate, Test, (FAIT) the next process must obviously be test. However, if System Integration is viewed as a continuous process, as opposed to a discrete point in time, and yet unverified by test, then test must be taken as a part of the Integration Process, i.e., it is a subprocess, as previously defined.

In this context, there are internal and external system integration requirements to be verified and validated by interoperability testing in Development Test/Operational Test (DT/OT).

In the ecosystem view, the integration process will continue, as system integration problems are defined, corrected, and verified. Post IOC will include Engineering Change Proposals (ECPs).

Reducing the number of problems that require ECP's in one objective of documenting the SIP.

Thus with the final system integration report, and an assessment of integrated system performance, comes Milestone III full rate production decision, so the next process might be defined as the decision process leading to milestone III.

The rhetorical question for this draft: Is integration completely accomplished before validation of integration is accomplished? At any rate the next steps in the SIP become:

**TEST: CONTRACTOR DEMONSTRATIONS; DT&E; OT&E**

**TEST REPORTING (Verification & Validation)**

## 10. OUTPUTS & CUSTOMERS

### OUTPUTS

**FULLY INTEGRATED SYSTEM**

+ Form, fit and funtion interoperability regarding internal interfaces
+ Form, fit and function interoperability regarding external interfaces
+ Integrated System Performance Met
+ Form, Fit, Function Validation and Verification of Fully Integrated System
+ Final Developmental Test and Evaluation
+ DT/OT Transition Report
+ Operational Test & Evaluation

**CUSTOMERS (Internal and External)**

**INTERNAL**

**Program Management**
Revised Program Master Plan (PMP)
Revised System Requirements
System Integration Management Status Reports
Integrated Program Summary (IPS) Annex D

**Systems Engineering**
Revised Systems Engineering Management Plan (SEMP)
Revised System Concept
Revised Service Use Profile
Revised Test & Evaluation Master Plan (TEMP)
System Integration Assessment Results
+ Verification (DT: effectiveness and supportability)
+ Validation (OT: Operational Effectiveness and Suitability)

**EXTERNAL (Fully Integrated System that satisfies user needs/ORD)**

**OPTEVFOR**
**JT&E Group**
Fleet User

## 11. EXIT CRITERIA

### PHYSICAL INTEGRATION COMPLETE

Assembly Complete at System Level
Interface Control Documentation Complete
Components verified to subsystem level
Contractor Demo/Tests Complete
Test Readiness Review Complete

## 12. TOOLS REQUIRED

**ASSEMBLY**

Manufacturing Tools
Facilities and Resources for System/Subsystem Integration Test & Evaluation

**VERIFICATION & VALIDATION OF INTEGRATED SYSTEM PERFORMANCE**

System Effectiveness Modeling and Simulation
System Effectiveness Data Base
Operational Suitability and Supportability Modeling/Data Base

## 13. METRICS & MEASURES

NAWC DT/OT Transition Report Requirements mandates (a check in the box to ensure) that **"the system was tested and evaluated and all deficiencies in the following areas" are correctly reported:**

**System effectiveness and capability ... in terms of performance ...**

**System Integration & Software integration ... interoperability**

**The ilities, etc**

Level of Integrated System Performance indicates level of system integration. System Effectiveness a measure of Integrated System Performance. Thus the following System Effectiveness metrics are identified as applicable metrics & measures to verify and validate that the system integration/system engineering is complete at the internal integration level, and that the system is ready to proceed to the validation process, e.g., the examination of external and internal interfaces in OT&E**.**

**SYSTEM EFFECTIVENESS (Integrated System Performance Metrics)**
+ Operational Suitability Measures
  Operational Availability (Ao) or readiness
  Operational Reliability (Ro) or dependability
+ Supportability Mearsures (RAM)
  System Reliability (R)
  System Maintainability (M)

Inherent Availability (Ai)
+ Operational Capability (Co) Measures
Operational Effectiveness
Survivability (S)
Performance/Design Adequacy (Da) Examples
* Aerodynamic Range or Endurance (Maximum Range/Expected Value)
* Radar/Radio-Data Link Range (Maximum Range/Expected Value)
* E/O-IR minimum resolution distance (Maximum Range/Expected Value
* Probability of Kill (Maximum Range / Expected Value

**NOTEs**:

(1) Per SECDEF Memo of 29 June 94, “Specs and Standards, New Way of Doing Business” [Use performance specifications and standards], trickle down documentation requires that “Performance” be identified as Process Capability (Cp) Bell Curves per AMC Pamphlets 715-17 (Guide for the Preparation and Use of Performance Specifications) and 715-16 (Program for Continuous Process Improvement); Hard metrics and their visualization as Cp Bell Curves provides the basis for Continuous Process Improvement (CPI). The Cp Bell Curves as outlined also allow comparison of actual capability with user requirements for integrated system performance. Thus Cp identification and documentation provides a check on system integration status. The Cp Bell Curves as outlined in AMC Pamphlet 716-16 (CPI) are the same Cp Bell Curves outlined in “The Memory Jogger: Pocket Guide of Tools for CPI”) p.64 - 68.

(2) Per USD(A&T) Memo of 28 April 95 (“Reengineering the Acquisition Oversight and Review Process”) and the requirement for stretch metrics/goals on an Automated Information System (AIS), the system effectiveness metrics outlined above, become potential candidates for the mandated stretch metric/goals.

## 14. VOICE OF THE CUSTOMER

“Who are the customers?” has been a controversial and often debated subject. To provide a “first cut” at discussing “voice of the customer”, first the customer(s) must be identified. Identification should be broken down into external and internal customers.

Quantitative metrics to measure customer expectations are system effectiveness metrics noted in paragraph 13, above, that measure integrated system performance.

## 15 VOICE OF THE PROCESS

Actualizing the system integration process in the context of the system engineering process has been historically vague, and is frequently considered an art as much as a science. One reason for this appears to be lack of integrated system performance measurement: that is tracking of system engineering metrics has not been done on a consistent well-defined basis. The results of system engineering, in terms of System Integration Process as reflected by system effectiveness, were treated subjectively, almost conceptually, more than pragmatically or being data-driven.

The Voice of the process calls for a data-driven set of system effectiveness metrics that tracks the results of the system engineering - system integration process, in terms of integrated system performance. A first cut at such a set of metrics is provided in section 13. Remarks regarding process capability (Cp) identification, and Continuous Process Improvement (CPI) apply: the Cp curves of the integrated system become the visual voice of the process, in terms of system effectiveness, suitability, supportability, and performance. These Cp Curves also become the visual voice of the customer, when the customer is pushing technical requirements that result in operational outcome that satisfies the ultimate user requirements. See reference [7]. This is true even when the customer doesn't understand the technical requirements, or constraints, in terms of cost.

The Voice of the Process also calls for distinctions between role of the government and role of the contractor. In "new way of doing business" the prime contractor will have the prime responsibility for system integration. In discussion of this process development, the roles and missions question arose: Are we going to be just an acquisition house?

## 16. DETAILED PROCESS DESCRIPTION

**16.1 Process Overview.** During System Integration Process (SIP) development and documentation discussion, a macro overview was developed around processes and plans that lead to system integration**.** (See NAVAIR S&E INST 5451.2)

There is general agreement in the literature, and in discussion that System Engineering Process (SEMP) leads the System Engineering Process (SEP), leads the system integration process, all of which result in system effectiveness. That is system effectiveness is a direct measure of SEP/SIP and an indirect measure of SEMP.

Plans That coincide with the processes are the System Engineering Management Plan (SEMP), the System Engineering Implementation Plan (SEIP) and the System Integration Plan (SIP). It was also instructive to assign the NAWCAD SE Codes as the responsible agents for the processes and plans. The break-down put on the blackboard during discussion looks like this:

| | | | | |
|---|---|---|---|---|
| Plans: | SEMP | | SEIP/SIP | (Metrics/Measures) |
| **Process Overview:** | **SEMP =>** | **SEP =>** | **SIP =>** | **System Effectiveness (Integrated Performance)** |
| NAWC SE Codes: | 4.1.1 | 4.1.2 | 4.1.2 | 4.1.3/4.10 ( M&S using Metrics) |

**16.2 Importance of System Integration by Design**

While System Integration in the Design stage is not the subject of "conduct system integration" in the physical sense, Design Integration is an acknowledged prerequisite. The equivalent to physical integration in the design stage is Fabrication, Assembly, Integration, and Test (FAIT) (M&S) of the paper design. System Integration begins when integrated system performance requirements are established.

A distinction between design integration and physical integration is provided by the Bob Olson "V" model, depicted below. System integration begins as a continuous process, and the system is decomposed down the left side of the V, through progressive decomposition, and design synthesis to the "cut metal/stamp out materials" stage, at which time FAIT is begun at the component level. Reaching the bottom of the V ends the design stage and begins the physical fabrication stage.

**External Interface Definition** **IOC: Integration to External World**

V

**FAIT**

FIAT continues up the right side of the V progressing from FIAT in component stage to the subsystem through complete system integration, it terms of form, fit, and function, represented by an assembled system. With successful completion of DT/OT and verification and validation of the integrated system, in terms of form, fit & function, as demonstrated by integrated system performance, the system is at the initial operational capability (IOC) milestone, and is deployed. Does integration [problems] stop here?

**16.3 Summary of what "Conduct System Integration" Process Involves**:

Bottom line Distinction: "Conduct System Integration" Process is defined as processes on the right side of the **V**, and is conditional on Design Integration Process, which is defined as the processes on the left side of the **V**. The total system integration effort is a continuous process, not a discrete event in time, and is an integral part of the system engineering life-cycle process.

**17. METHODS**

The extent of system engineering and system integration will be determined by integrated system performance. System effectiveness parameters normally define integrated system performance.

A system effectiveness model to assess integrated system performance will be developed in the design stage. System effectiveness data will be maintained in an integrated data base.

The physical solution will be compared to the design solution; Process Capability (Cp) methods called out in AMC Pamphlets: “Guide to Writing a Performance Specification” and “Continuous Process Improvement” will be made to compare requirements with capabilities.

Quantification of system effectiveness parameters will be used to define the level of integrated system performance.

**18. EXAMPLES.** There is some reluctance to discuss worse case examples. It is from such examples the most can be learned.

### 18.1 How Not to Do SIP: UAV-MR

GAO: “UAV-MR Components do not fit.” The UAV PMO went its way building a platform, under the “truck” concept, under a prime contractor. Another contractor was assigned as prime contractor to provide a sensor to go in the truck. The sensor had growth problems. Some how there lapsed a clear definition of external interface for the form and fit, of the “form, fit, and function” requirement. Probability of meeting the functional requirement thus became zero.

There also lacked a clear distinction of who was in charge of the overall system; In the new way of business the prime contractor will be responsible for the integration. One question that lingers in this example: who was the prime contractor.

### 18.2 How SIP is being done: TIER UAV Program

The TIERII+/TIERIII is an advanced concept technology demonstration (ACTD) using “New Way of Doing Business” Guidelines.

The TIERII+/TIERIII- Test Director is Cdr Phil Brennan; his lead engineer is Mr. Jeff Semenza. Both are NAWCAD Pax 4.1.5 Personnel attached to the TIER program.

Cdr Brennan and Mr. Semenza will be asked to comment on the efficacy of this document, by their experiences with evaluating TIER System Integration issues. Objective will to determine value-added to TIER Program System Integration Process, and to make value-added additions to the System Integration Process documentation, based on the TEIR System Integration approach.

## 19. DEFINITIONS

**Configuration Baseline**: The configuration at a point in time recorded in documentation that fully describes the functional, performance, interoperability, interface requirement, and physical characteristics, as appropriate to the stage of the life cycle (P1220)

**Integration:**
**(1)** The act of putting together as the final end item various components of a system. The Integrator in acquisition is the "prime contractor". (DSMC)
**(2)** The merger or combining of one or more components, parts, or configuration items into a higher level system for ensuring that the logical and physical interfaces can be satisfied and the integrated system satisfies its intended purpose (IEEE P1220)

**Integrated Data Base**: A repository of storing all information pertinent to the system engineering process to include all data, schema, models, tools, technical management decisions, process analysis information, requirement changes, process and product metrics, and trade-offs. (IEEE P1220)

**Integrated Program Summary**: A DoD component document prepared and submitted to the Milestone Decision Authority in support of Milestone I, II, III, and IV reviews. It succinctly highlights the status of a program and its readiness to proceed into the next phase of the acquisition cycle. (DoD 5000.2)

**Interface**:
**(1)** The functional and physical characteristics required to exist at a common boundary or connection between persons, or between systems, or between persons and systems. (DSMC)
**(2)** Requirement: Functional and physical requirements and constraints at a common boundary between two or more functions or items. (EIA-632)

**Interface Management**: Approach and methods planned to manage internal interfaces appropriate to the level of development to ensure that external interfaces (external to the project or at a higher level of the functional or physical architecture) are managed and controlled. (IEEE P1220)

**Interface Specification**. The description of essential functional, performance and physical requirements and constraints at a common boundary between two or more functions or physical items (IEEE P1220).

**Operational Availability (Ao):** probability that the system is ready to perform its specified function, in its specified operational environment, when called for at a random point in time (OPNAVINST 3000.12)

**Operational Capability (Co)** a system's operating characteristics (range, payload accuracy and the resultant ability to counter the threat (OPNAVINST 3000.12); conceptually equivalent to Process Capability, i.e., Co = Cp (AMC Guide for Continuous Process Improvement)

**Operational Dependability (Do):** probability that the system, if up at the beginning of the mission, will remain up throughout the mission; also known as operational mission reliability (Ro) (OPNAVINST 3000.12)

**Subsystem:** An element of the physical or system architecture, specification tree, or system breakdown structure that is a subordinate element to a product and is consists of one or more assemblies, and their products and services.

**System**:
**(1)** The top element of the system architecture, specification tree, or system breakdown structure that is a subordinate element to a product and is comprised of one or more products and associated life cycle processes and their products and services. (IEEE P1220)
**(2)** The top element, that is comprised of one or more products and associated life-cycle processes and their products and services. A combination of subsystems that includes, hardware, software, and human interface, that when properly integrated, produces a desired result, that satisfies the consumer of the result.

**System Effectiveness (SE)**:
**(1)** A statistical measure of the extent a system performs specific mission requirements in the intended support and operational environment, as a product of operational availability (Ao), reliability (Ro), and capability (Co) over time, usually the expected value of same. (OPNAVINST 3000.12 + Habayeb- “System Effectiveness” + DSMC)
**(2)** Measures of the extent to which a system can be expected to satisfy customer needs and requirements; SE depends on factors including availability for use, and dependability and capability in operation. SE and its factors may be used as decision criteria and the values may be used as requirements (EIA-IS-632).
**(3)** The combined effects of the system’s operational availability, dependability and capability; Operational Availability (Ao) is a probability that a system is up and ready to perform as intended; Operational dependability (Do) or reliability (Ro) is a probability that a system is able to complete a mission that it has started; Operational Capability (Co) refers to the system’s operating characteristics (range, payload, accuracy, and the resultant ability to counter the threat; in laymen’s terms SE answers the question” Did it do what is was intended to do successfully? per the function SE = Ao * Do * Co? (OPNAVINST 3000.12)
**(4)** A measure of the extent to which a system may be expected to achieve a set of specific mission, requirements, and which may be expressed as a function of availability, dependability, and capability. (NWC TP 6740)
**(5)** The Measure of the extent to which a system may be expected to achieve a set of specific mission requirements. It is a function of availability, budgetability, dependability and capability. (Note: spell-check did not recognize “budgetability”)

**(6)** A measure of the extent to which a system can be expected to complete its assigned mission within an established timeframe under stated environmental conditions. (RDT&E Management Guide)
**(7)** System effectiveness is a combination of operational effectiveness and operational suitability (Inferred by inductive reasoning, per Title 10, USC 2399 OT&E definitions.

**NOTE**: One purpose of this list of system effectiveness definitions is to point out that there is no quantifiable standard one can reference, hence definition (1).

**System Engineering (SE):**
**(1)** The management function which controls the total system development effort for the purpose of achieving an optimum balance of all system elements. It is a process which transforms operational need into a description of system parameters and integrates those parameters to optimize the overall system effectiveness (DSMC)
**(2)** An interdisciplinary collaborative approach to derive, evolve, and verify a life-cycle balanced system solution with satisfies customer expectations and meets public acceptability [cost/effectiveness?] (IEEE P1220)
**(3) The application of the mathematical and physical sciences to develop systems that utilize economically the materials and forces of nature** for the benefit of mankind. (IEEE Standard Dictionary of E/E Terms; IEEE/John Wiley & Sons; 1978) [**Bolding** to emphasize the distinction between System engineering and management]]
**(4)** Transformation of an operational need into an effective and affordable operational system through an iterative process of technical definition, synthesis, analysis, design, testes, evaluation, and production control. Included is the integration of all physical, functional, and program requirements with reliability, maintainability, safety, survivability, human and other factors in a manner that optimizes total system performance, quality, cost/effectiveness and supportability. Figure provides other details of the systems engineering process. (S&E INST 5451.2)

**NOTE**: The DSMC definition of SE in terms of "management" and "integration/optimization" invokes the double entendre frequently applied to the term "engineering." In the case of defining management as "system engineering", the social process definition of engineering, as in "Re-engineering the Corporation," is invoked. In the case of defining system engineering as "integration/optimization" the more literal process definition of engineering is invoked. The distinction to keep in mind, is that in the literal sense of the process of engineering, system engineering management is not system engineering per se; In terms of the oft applied System Engineering is both an "art and science' - system engineering management is the [social] art, and system engineering is the science [physics and statistical solutions]. These distinctions are important because once realized, they allow the reader to sort out what is system engineering standard processes, and what is system engineering management standard processes. This also provides an explanation for the double entendre use of "integrate" system functions and "integrate" the technical activity that integrate the system functions, i.e. the IPT; the former necessitates science and engineering expertise; the latter necessitates expertise in the social science of system engineering management.. The difference between systems engineering and its management is distinguished in NAVAIR INST 5451.2 (Systems and Engineering Technical Support Implementation). See previous and following definitions.

Systems Engineering Management: Management of the Systems Engineering Process and involves application of business disciplines such as cost and schedule controls in decision making. It comprises all systems engineering related tasks performed by NAVAIRHQ program managers, assistant program managers, and functional managers/specialists. Policy direction, development of acquisition strategies, management of resources, conduct of program design reviews and evaluation of program performance are tasks associated with system engineering management.

**Systems Engineering Management Plan (SEMP)**
A comprehensive document that describes how the fully integrated engineering effort will be managed and conducted.

**Systems Engineering Master Schedule (SEMS)**
A compilation of key accomplishments requiring successful completion to pass identified events. Accomplishments include major and critical tasks, activities, and demonstrations, with associated accomplishment criteria. Events include technical reviews and audits, demonstration milestones, and decision points. Successful completion is determined by the measurable criteria defined for each accomplishment. Examples of the criteria include completed work efforts and technical parameters used in TPM Quantitative inputs into program decision points comes from the data associated with the accomplishment criteria.

**System Engineering Process**:
**(1)** A logical sequence of activities and decisions transforming an operational need into a description of system performance parameters and a preferred system configuration (Test and Evaluation Management Guide, DSMC)
**(2)** An iterative process of system analysis, allocation, design, synthesis and evaluation. The objective of this process is to achieve an optimized operational air system design. ( NAVAIR S&E INST 5451.2)

**Systems Integration**:
**(1)** A component of the system engineering process that unifies the product components and the process components into a whole ... ensuring that the hardware, software, and human system components will interact to achieve the system purpose or satisfy the customer's need. (Grady: "System Integration")
**(2)** System Integration and Test is discussed as a subset of the continuous System Engineering Process (SEP) as "Fabrication, Assembly, Integration & Test" SEP ... SEP. Discussion under System Integration indicates: "integration is conducted to ensure that the combining of the lower level elements results in a functioning and unified higher level system element with logical and physical interfaces satisfied. ... At each level of assembly and integration the components ... system should be subject to testing to ensure operational effectiveness, interface compliance, supportability, etc. See definition of integration, above; also requirement for system integration testing during DT&E, to meet system engineering check in the blocks, for the DT/OT transition report, paragraph 13., above.

**Notes**:

(A)  Grady offers many views of what **System Integration** is; this particular view seems to suit most, the direction in which we are headed.
(B) Otherwise, a definition of **System Integration**, good or bad, is hard to find to find in the literature; one has to go to “integration” and “system” - then figure it out for himself.
(C) In developing the SIP, the same dilemma is encountered in DoD/USN references.  One must infer what needs to be done and put it on paper.   See references [1] - [15] for additional insight.

**Systems Integration Plan**:  Describes the approach and methods by which the system is assembled and integrated (IEEE P1220).

## 20. ASSUMPTIONS

The System Integration Process (SIP) leads to integrated system performance. Integrated System Performance is reflected and defined by the level of System Effectiveness.

System Engineering Management Process leads the system engineering process (SEM) and system integration process (SIP); ALL leads to integrated system performance measured by system effectiveness. System Effectiveness and cost effectiveness are the ultimate measure of SEMP => SEP => SIP => SE. See detailed discussion in paragraph 16.

Detailed description of SIP, and additional assumptions will be added, when SEM Process Document becomes available, as the umbrella document(s).

In the "New Way of Doing Business" the Prime Contractor will normally be responsible for system integration, and the government will be responsible for some reduced level of oversight, TBD. Level of oversight will be determined by the SEST, per S&E Inst 5451.2 or SEST equivalent (IPT?); reference [7] and related references are germane.

"Conduct System Integration" doubles as a training document, that could be presented to an engineer new-hire, with the purpose of orienting him to the SIP.

Development and Documentation of the SIP will continue under rules of CPI.

## 21. TAILORING GUIDANCE

Tailoring guidance is needed for the system integration process relative to other processes under examination and development, including the system engineering process as the overarching, higher-level process, parallel processes, and supporting processes. These include the requirements developmental process, and the validation and verification process which use metrics & measures that ascertain the extent of successful integration, by defining integrated system performance.

A number of questions relating to tailoring guidance of the system integration process are presented in paragraph 27.

## 22. AGENTS

Program Management (1.0)
System Engineering Management (4.1/4.1.1)
System Development and Integration (4.1.2)
- It was noted in discussion that there is a fuzzy line between 4.1.1 and 4.1.2, and

that sometimes the SEP/SIP processes overlap/are handled by either or.
Facilities and Simulation (4.1.3)
Modeling and Simulation (4.10)

## 23. TIMELINE

*Discuss any applicable timeline for executing the process; Acquisition Reform mandates that the timeline be shrunk considerably; CPI is the means to the end.*

Stretch metrics/goals mandated by USD(A&T) Memo of 28 April 95 may provide the means to CPI, that would reduce timelines of acquisition. See paragraph 13.

The System integration process (SIP) is a continuous process, that begins in the concept stage and continues throughout the life cycle, in parallel with system engineering. Checks for system integration during SIP are usually timed as milestone events.

Conceptually, USD(A&T) advocacy for stretch metrics/goals on an automated information system could result in continuous checks, paralleling the continuos nature of the SIP.

## 24. STANDARDS AND HANDBOOKS

### COMMERCIAL STANDARDS:

+ IEEE P1220: Standard for Application and Management of the Systems Engineering Process.

+ EIA IS 632: System Engineering (Commercial translation of MIL-STD-499A (System Engineering Management)

+ IEEE 1498/EIA-640 Software Development Management DRAFT

### MILITARY STANDARDS:

+ MIL-STD-498: Software Development and Documentation (Approved for interim use, as there was no equivalent commercial standard available, with IEEE 1498/EIA-IS-640 under development).

+ MIL-STD-721: Reliability, Availability and Maintainability definitions (Was not placed on the initial "hit" lists; these terms do not appear to be defined well enough in existing STDs, such that they can be quantified with consistency.)

**HANDBOOKS**

+ Test and Evaluation Management Guide (DSMC)

+ RDT&E Management Handbook (USN, 11th Edition)

## 25. APPLICABLE TRAINING AND EXPERIENCE

**TRAINING**

+ System Engineering Course (Contractor OTS); Relation to DSMC SEMC Course?

+ Defense Systems Integration: Methodology & Effectiveness Analysis; GWU Continuing Education; Instructor: Dr. Abdul Habayeb; See paragraph 26 and 27 below.

+ Other training to be developed as required/when identified as a SIP deficiency

**EXPERIENCE/OJT**

+ Defense Acquisition Workforce Improvement Act (DAWIA) Qualification Months (System Engineering)

+ System Integration Management in a Major Program

+ System Integration Management in a Systems Engineering Support Team (SEST)

+ International Council on System Engineering (INCOSE). A recently chartered organization that has become increasingly recognized as the foundation of commercial system engineering methods and practices. Exposure to system engineering practices in local chapter meetings and at national symposiums provide considerable background and training. Numerous technical committees also provide the basis for more focused attention to system engineering matters. Membership is coming to be viewed as a prerequisite "credential" for using the label "system engineer." Regarding the latter, certification of system engineers is one subject under debate. Probably a good idea. INCOSE Proceedings and members will continue to be a resource for documentation of the system engineering processes.

## 26. EXPERT ADVICE

In a telephone conversation with Dr. Abdul Habayeb, recognized System Integration Expert (NAVAIR 530TG), Dr. Habayeb summarized the relationships of System Integration, System Engineering, and System Effectiveness, as follows:

The System Integration Process is essentially a system engineering process. It is not mutually exclusive of system engineering, and its measure is system effectiveness, just as the measure of system engineering is system effectiveness.

**NOTE**: In discussions with Bob Olson, we think it would be a good idea to have Dr. Habayeb "chop" this document, probably appropriate after about version 6.

Additional Expert advice may be available through the International Council on System Engineering (INCOSE). Bob Olson and John Marshall are currently interacting with government and non-government POC's including: John Snoderly (DSMC SEMP POC, and Richard Wray, SEP POC. Experts consulted by their writings include.

+ Richard B. Wray: "Process Description for a New Paradigm in Systems Engineering." This paper provides a good basis for examining the SIP in relation to the SEP. Observations include:

++ SEP integrates design and support activities/exposes potential interface problems.

++ SEP must oversee the development of subsystems in detail design and that they are built right so they can be integrated to meet system requirements.

++ SEP must make sure the system is delivered right, validate that it meets users' needs, and that the customer is satisfied.

++ SEP must integrate and optimize system elements.

++ SEP leads integration and verification and validation

* Verification is assuring that the system meets specified requirements.
* Validation is assuring that the system meets the users' needs

+ Jeffrey O. Grady: "System Integration" This book defines System Integration in a number of ways. Implementing Grady's unique concept would require reading a book; probably not practical, but good background; related short courses might be interesting to attend.

+ Joe Defoe: "Pragmatic Principles of System Engineering" is a short paper that summarizes the System Engineering Process:

++ Use effectiveness criteria based on needs to make system decisions

++ Establish and manage requirements

++ Identify and assess alternatives to converge on a solution

++ Verify and Validate requirements and solution performance

## 27. SIP DOCUMENTATION INFORMATION

**SIP POC'S:** John Marshall [AD Pax]/John Metzer [AD War]

**SIP DOCUMENTATION TEAM:**

Robert Olson [WD]
Albert Ortiz [AD]
John Marshall [AD]
John Metzer [AD]
Robert Skalamera [AD]
John Kichula [AD]
Cdr Phil Brennan [AD]*
Mr. Jeff Semenza [AD]*
* Will be asked to comment on applicablity to TIER UAV Program (See 18.2)
Dr. Abdul Habayeb [NAVAIR] (invited expert; see paragraph 26.)

**SIP DOCUMENTATION VERSIONS**

**WORD DOCUMENT**
**REVISION NUMBER:** 6.1
**LAST REVISION DATE:** 1 Sept 95

**TEMPLATE**
**REVISION NUMBER:** 02
**LAST REVISION DATE:** 1 Sept 95

**FLOW DIAGRAM V1**
**REVISION NUMBER:** Generic Flow Diagram Courtesy Bob Olson
**LAST REVISION DATE:** 30 Aug 95

**SUMMARY OF PREVIOUS VERSIONS (**Actions by John Marshall after V0 was given a final tweak by John Metzer; V0 was then put in Bob Olson's "Risk Management" Shell, which was used a standard guideline.**)**

V0: John Metzer's version discussed in 21 July Meeting/w updates.

V1: E-Mailed to Bob Olson and John Metzer for Parallel Processing/Comments

V2: Ditto, cc to Al Ortiz (27 Aug 95)

V3: Ditto, 28 Aug 95 Completed Word Doc Draft for 29 Aug AD WAR mtg

V4 : 29 Aug Hard Copy for AD WAR Meeting; inclusion of 5451.2 Info in 19.

V5: 31 Aug 95 E-Mail to Metzer/Olson for Parallel Processing, 1 Sept Deadline

V6: 1 Sept 95 V6.0 E-Mailed to Bob Olson and John Metzer for Labor day Preview.
6 Sept 95 V6.1 E-Mailed to Documentation Team, as noted above, for "Chop".

## ISSUES DISCUSSION

1. Should "integration" in the design stage be considered separate from "integration" immediately following the fabrication and assembly level. This question arose out of discussion between Bob Olson and John Marshall; This follows John Metzer's observation that "In a more pragmatics sense, Development and Integration Management is the preceding process. RESOLUTION: Primary Consideration: Physical Integration; Design is preceding/supporting process and input to SIP.

2. In the view of the system engineering process managers, How does system integration relate to system engineering and system effectiveness? As generalized in paragraph 16. Bob Skalamara: We are using bottom-up approach.

3. Where else is the system engineering process and system effectiveness outcome, resulting therefrom, considered in System Engineering Process identification and documentation? General answer: In over-arching processes being developed: Generalities of SEMP TBD.

4. How does the System Integration Process interleave with the System Requirements/ Operational requirements process? (POC: John Kichula?): John Kichula not present at 29 Aug NAWCAD War Meeting: Bob Skalamera: (paraphrasing) As system requirements evolve and change, SIP will be affected by [external/internal interoperability/interface] changes in the system requirements. Thus this must played off/iterated in the continuous SIP.

5. Bob Olson: you need flow-charts for the SIP. Working.

6. Like to have this process link with SE Management process. Bottom-up development applies: SEMP TBD. With availability of the SEMP I.D. and Documentation, next iteration of SIP, should begin top-down.

7. Rhetorical question, owing to continuous nature of SIP: What is process immediately preceding and immediately following system integration; another way of asking question: Is FAIT one process, with subprocesses; are FAT processes sub, supporting, pre-, post-; can they fall in more than one category? Number of people = number of perceptions.

8. Add EIA and IEEE examples of program and system description documents.

9. Review against established outline.

10. Expand paragraph 16 & 17, on availability of parallel supporting processes and over arching processes.

11. Add references.

12. Add additional definitions to definition section, as appropriate

13. Add additional examples- UAV TIER Program applicability.

14. Accommodate the fact that only an assessment of System Integration indicating completion, completes System Integration; How does this relate to Interface control document?

15. Address the fact that the current quantitative System Integration approach does not address multiple System Integration sources, none of which get out of bounds but together contribute to a problem. HOW, or is this related to overall system effectiveness?

16. Review document for missing entries and fill in.

17. Where is a good definition of system integration to be found? Best answer so far: combine definitions of system and integration; there are plenty of each, but not much system thought.

18. Should there be an acronyms section?

## 28. REFERENCES AND BIBLIOGRAPHY

### 28.1 REFERENCES

### Preface: Integrated System Performance Verifies & Validates System Integration Process

[1] Secretary of Defense Memorandum of 29 June 1994, Dr. William Perry; Subj: Specifications and Standards: New Way of Doing Business [Use Performance Specifications and Standards].

[2] USD(A&T) Process Action Team (PAT) Report of April 1994: "Military Specifications and Standards: Blueprint for Change" (basis of [1]): Do CPI with I.D. of Cp."

[3] U.S. Army Pamphlet 715-16: Continuous Process improvement (CPI) (Ref of [2])

[4] U.S. Army Phamplet 715-17: Guide to Writing a Performance Specification (Ref of [2]): OASD(P&L), Mr. Greg Saunders, et al, has indicated that this document was being re-written as a DoD Instruction. In "New Way of Doing Business" this could essentially replace DoD 5000.

[5] Undersecretary of Defense (Acquisition & Technology) - USD(A&T) Memorandum of 28 April 95; Paul Kaminski: Subj: Reeingineering the Acquisition Oversight and Review Process: Develop Automated Information System that will pass near real-time, stretch metrics/goals to decision makers for acquisition and employment decisions {DAB/Mission Planning] ; Lingering question regarding A&T mandate to grade contractor response to RFP's on ***past performance***: What is DoD/USN "standard" to grade contractor on ***past performance***?

[6] OPNAVINST 3000.12, Operational Availability and System Effectiveness (SE)f CNO(N432) POC: Dan Fink. De Facto, an Operational/Functional Performance Specification, along the lines of [1] - [5] consistent with refs [7] - [15], below. What happens when [1] - [15] are neglected? See References [16] and [17].

[7] ASN(RDA) Memo of 27 Jul 94 on Navy Implementation of Defense Policy on Specifications & Standards Reform per SECDEF Memo of 29 Jun 94: Following appears to apply to the SIP:
(1) Performance or performance-based specifications are those specifications that define equipment or systems in terms of observable and measurable operational and support characteristics and [integration/interoperability] interfaces that allow the product to effectively and efficiently perform its mission, per DoD 5000.2, Part 3, section C7.
(2) Configuration Management: To the extent practical, program managers shall maintain configuration control [HW/SW ICD's] of functional and performance requirements only, giving contractors responsibility for detailed design [integration]. Such requirements will be used to control the **form, fit, and functional [integrated]** characteristics, while minimizing [detailed] design constraints on the contractor.
(3) Contract oversight: Navy activities are directed to reduce government oversight by proposing alternatives to military-unique quality assurance items.

[8] Systems and Engineering Technical support Implementation; Systems and Engineering Group Instruction 5451.2, dated 21 Sept 1987; AIR-05A1; J.J. Bettino; The SEST “bible” still has some good stuff in it.

[9] “Measures of Effectiveness in Systems Analysis and Human Factors" by Ron Erickson; NWC TP 6740; Sept 1986. Amplifies OPNAVINST 3000.12.

[10] “System Effectiveness” by Dr. Abdul Habayeb (AIR530TG); Permagon Press. Amplifies OPNAVINST 3000.12; is taught as a system integration short course by GWU continuing education.

[11] “Fundamentals of Aircraft Combat Survivability Analysis and Design” by Professor Robert E. Ball; AIAA Educational Series. Equivocates Operational Effectiveness with Operational Capability (Co). Defines Survivability (S) as Co in the defense, and Mission Attainment/ability Measure (MAM) as Co in the Offense. Relates the two as Co = S * MAM = MOMS = Measure of mission success.

[12] “The Memory Jogger” - A Pocket Guide of Tools for Continuous Process Improvement; 1988; GOAL/QPC; Methuen, Mass. A good 4 page summary of reference [3[ can be found on pages 65 - 68.

[13] Defense Acquisition Reform: DoDD 5000.1; B: DoDI 5000.2; C: DoDI 5000.2M; 23 Feb 91; DOT&E/USD(A)

[14] Memorandum of Agreement on Multiservice OT&E and Joint T&E; Apr 90; Agreement on how to test RAM factors.

[15] Reliability Engineering Handbook; Vol I; Kececioglu; Prentice Hall; Advocates same system effectiveness equation of OPNAVINST 3000.12; see ref [9] and [10]

[16] UAV-MR Components Do Not Fit; GAO R-242779; March 25, 1991

[17] WEAPON SYSTEMS: "Quality of DoD OT&E & Reporting"; GAO/PEMD-88-32BR; July 1988.

[18] Flight Test & Engineering Group (FTEG) Report Writing Guide; March 1994; NAWCAD Pax;TID. The Sysstem Integration word (reporting requirement) appears in the DT/OT Transition Report as a check in the block.

[19] TBD

[20] IEEE P1220: Standard for Application and Management of the System Engineering Process (SEM). Final Draft Copy (Edition has actually hit the street). Generally the preferred commercial

SEM Standard. There is some concensus that there is no commercial System Engineering (SE) Standard, per sa; Discussion regarding distinction between SEM and SE in paragraph 19 applies. Those who are not in consensus are stuck in the management paradigm, and have begun to define management as engineering, i.e., social engineering is also considered “system” engineering in some circles. See DSMC definition of system engineering, paragraph 19.

[21] EIA-IS-632: System Engineering (Working Draft used); This Document is obstensibly a SEM Document; In the balloting process, a negative ballot was cast, with aggreement to change to positive if Document was Changed to System Engineering Management. (The same title of MIL-STD-499, from which it evolved) Answer: “Too Political” to change the title

[22] MIL-STD-498; Software Development and Documentation; 29 June 94. Adopted as an interim Standared, for two years. while an [IEEE 1498/EIA 640] version is being developed.

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