SYSTEMS INTEGRATION OF SYSTEMS FOR LIFE SUPPORT

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Summary

Systems Integration (SI) is essential to the development and procurement of any large life support system. SI provides an organized, sensible, accountable, and workable approach to otherwise very difficult problems and issues found in life support systems. Implementation of SI combines systems engineering and systems management and

applies these to life support systems that may include 1) hardware, software, facilities, personnel, procedures, and training; and 2) the integration of existing and/or new capabilities to achieve specific goals and objectives. The sponsor and contractor must have a well articulated strategy for development and implementation of the SI program, including a systems development life cycle, risk assessment and management plan, quality assurance plan, development and implementation of an audit trail, a plan for management of subcontractors; a fully articulated approach to the conduct of SI programs. SI is defined and the role of SI in large complex life support systems is examined. A SI life cycle is developed that indicates the tasks that must be completed, a SI strategy for success is explored, some of the application methodologies for SI are examined, the characteristics necessary for configuration management are looked at, the relevant management characteristics are reviewed to see how disparate subsystems are brought together and tested, delivered, and these are all examined in light of risk management strategies.

1. Introduction

Systems integration (SI) is essential to the development of large life support systems. It combines the practice and application of systems engineering and systems management, involving the organization, management, and technical skills necessary for success in systems integration programs, to large life support systems. These concepts are utilized to address latent opportunities and problems associated with melding existing systems and new technologies to form more capable systems that are intended to take on additional tasks, exhibit improved performance, and/or enhance existing systems. The majority of contemporary life support systems are systems of systems, and this requires even greater attention integration principles, practices, and perspectives.

Typically, SI requires the coordination of pre-existing and co-existing system components with newly developed ones. The outcomes may result in the significant growth of these systems or the merging of two or more systems or the combining of existing system fragments with commercial off-the-shelf components or various combinations of these. At a tactical level, SI is involved with insuring that specific hardware/software components fit together smoothly in a stated configuration. Indeed at this level, SI is often referred to as "*configuration management*." But at a broader, more strategic level, SI is concerned with interpreting overall performance needs of a sponsor into technical performance specifications and ensuring that these system requirements are met.

1.4 Objectives for a SI Methodology

The objectives for a systems integration engineering methodology may be stated as follows:

1. to provide a suitable methodology that encompasses the entire integration program from requirements through design to construction to test and finally to deployment and maintenance;
2. to support problem understanding and communication between all parties at all stages of development;
3. to enable capture of design and implementation needs early, especially interface

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and interactive needs associated with bringing together new and existing equipment and software in support of organizes and enterpiises involved in all facets of the effort;

4. to support both a top-down and a bottom-up design philosophy;
5. to support full compliance with audit trail needs, system level quality assurance, and risk assessment and evaluation;
6. to support definition and documentation of all aspects of the program; and
7. to provide a framework for appropriate systems management application to all aspects of the program.

To fulfill these objectives there are certain minimal requirements that pertain to the sponsor/ client/sponsor and the contractor for the systems integration project. Systems integration activities may be viewed from the perspective of the sponsor/ client/sponsor or the contractor engaged to carry-out the SI contract. The sponsor/ client/sponsor must define the systems integration requirements, specifications, constraints, and variables in a manner that provides the means for a contractor to deliver the necessary systems and services required to fulfill the sponsor/ client/sponsor mission under the specific contract. The contractor engaged to carry-on the SI program must be able to understand the requirements documents, comprehend the issues associated with bringing together existing systems with new systems, and do so in an effective and efficient way so as to deliver the integrated product on-time and within budget.

Thus, SI personnel, both sponsor/ client/sponsor and contractor must be well prepared in systems engineering and management disciplines. Systems engineering and systems management combine hardware, software, facilities, personnel, procedures, and training to achieve specific goals and objectives. SI requires personnel who possess sound technical and management skills that combine to provide the ability to integrate technology and operations with technical and managerial direction. Systems engineering addresses tasks that are essential for the design, development, and operation of large life support systems. Systems management covers the tasks and related activities associated with planning, control, and operations to achieve the goals and objectives of a specific systems integration program.

SI is applicable to a wide variety of programs that range from the procurement of major socio-economic systems to medical care management systems to life critical support systems. Typical systems integration applications are for large scale programs that include hardware, software, facilities, personnel, procedures, and training, as these relate to the integration of existing and new capabilities to achieve specific goals and objectives. Systems integration programs have come to include the procurement of major Automated Data Processing (ADP) systems such as those associated with oceanography and ecology, Management Information Systems (MIS) programs such as those for the Environmental Monitoring and Assessment Program (EMAP), and business process re-engineering programs such as those found in most industries.

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1.5 Definition of Systems Integration

SI presents a logical, objective procedure for applying new and/or expanded performance requirements in an efficient, timely manner to the design, procurement, installation, and operation of an operational configuration consisting of distinct modules (or subsystems) each of which may embody inherent constraints or limitations. This definition of SI contains a number of key terms that require further explanation within the context of SI:

- "Logical, objective procedure": the SI process is clear to external observers and all steps have a built-in audit trail.
- "Efficient and timely": the SI process will not be unduly burdened with delays and bureaucratic procedures that increase cost to the client/sponsor and delay deployment of the system.
- "Design, procurement, installation, and operation": the SI process will be employed throughout the entire process. Life cycle costing will be considered together with retrofits, extension of system capability and the like.
- "Distinct modules with inherent limits or constraints": the concept of distinct modules with inherent limits or constraints is central to the concept of SI. System Integration is necessary when the configuration to be deployed includes devices with intimate connections to other devices previously deployed or to be deployed under a later procurement, particularly if these devices were designed and constructed de nova by subcontractors with only partial design responsibility for the overall system.

1.6 Role of SI in Systems for Life Support

The rationale behind the use of SI in the development and procurement of life support systems is to provide an organized, sensible, accountable, and workable approach to otherwise seemingly very difficult issues and concerns. Some of the attributes emphasized through the use of SI for such systems include:

1. development and utilization of a strategic plan for management and technical aspects of the program;
2. establishment of a complete audit trail;
3. assistance in meeting initially unrecognized needs (including changes in system requirements).
4. avoidance of under- and over-procurement;
5. development and utilization of risk management plans;
6. management of subcontractors to the same specifications as employed on the prime contract; and
7. provisions for future modification and expansion.

Application of a systems integration methodology provides an organized approach to carry-out the definition, development, and deployment of life support system, including systems management facets.

2. SI in Life Support Systems and an SI Life Cycle

The methodologies of systems engineering and systems management are incorporated to provide a formal approach applied to SI programs. This organized approach supports and sustains the use of an SI life cycle and provides for a smooth rational development

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of a SI program. A typical SI life cycle is generally comprised of a number of phases, usually seven (the minimum number is three and the maximum number unspecified) that range from the identification of requirements and the statement of specifications, to operational deployment of the system. Minimally, the system life cycle phases are requirements definition, design and development, and operations and maintenance. A seven phase life cycle that very commonly used in systems integration programs is as follows:

1. requirements definition and specification
2. feasibility analysis
3. system architecture development
4. management plan: program and project plan
5. systems design: logical and physical design
6. implementation: design implementation, system tests, and operational deployment
7. evaluation: system review and plan for replacement/retirement

This SI life cycle is both interactive and iterative, however, for simplicity of presentation it is depicted as a waterfall model as shown in Figure 1.

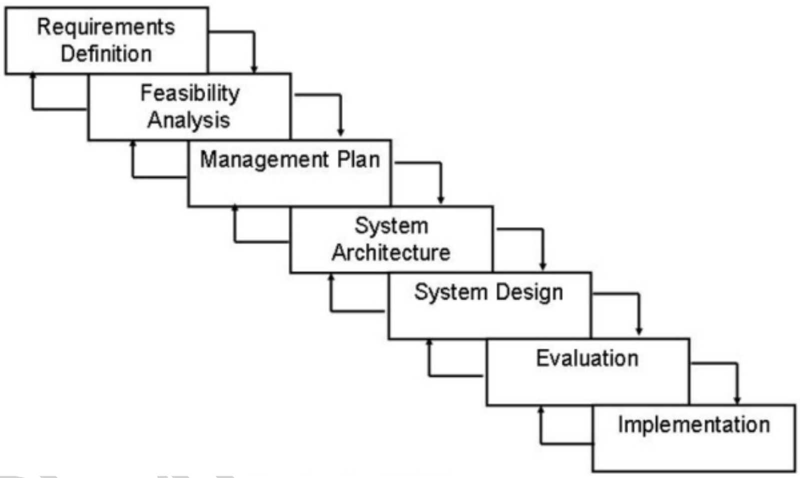

Figure 1: Systems Integration Life Cycle

Some of the primary activities that are conducted during each of the typical life cycle phases are noted below.

1. Requirements definition and specifications
    a. Definition of requirements by use
    b. Review of requirements for ambiguity, conflict, and other issues
    c. Development of systems specifications

The goal for requirements definition and specification is to completely define and correctly interpret the client's real needs. It sometimes surprises the systems integrator when the client/sponsor appears not to understand completely the system requirements being proposed, however, this should come as no shock. The client/sponsor is undoubtedly an expert in the area in which the system is to be constructed (or certainly should be) and there is no reason to expect that an expert in the particular technical area should also be an expert in system component design and integration, especially when the need is for new functionality to be incorporated in an existing system or several systems are to be coupled together with added functionality.

2. Feasibility analysis
   a. Determine the likelihood of successful system development and deployment
   b. Examine new technologies
   c. Assess risk and develop risk strategies

It is necessary to establish complete and consistent system performance criteria to determine feasibility as well as assess risk potential. Criteria must be developed on a *functional basis* using reference to existing configurations and systems only when appropriate and necessary. In the procurement of life support systems, there is an almost certain risk of not taking advantage of technology growth and change if functional bases for feasibility criteria are not utilized. It will not be possible to develop an audit trail that leads from the functional performance requirements of the client/sponsor to the final procurement choice, if feasibility criteria were not functionally based. Assessment of risk potential based on performance and technical characteristics constitutes one of the major activities during feasibility analysis.

3. System Architecture Development
   a. Describe functional system architecture
   b. Specify required technical capabilities

Just as is the instance with feasibility analysis concerning performance, it is necessary to specify system architecture and establish required technical capabilities for the system to be deployed. This is an especially critical activity for system integration in that the architecture selected will most certainly determine the ease or difficulty with which the ensuing system may be put together and made operational. Good systems architecture can also provide significant cost savings, especially during maintenance activities, as well as greatly increased system flexibility. We must be certain that we put architectural requirements in system specifications, emphasize the early satisfaction of these specifications, give incentives to use proven architectural concepts, and control architectural configuration over the life cycle of the system.

4. Management Plan: Program and project plan
   a. Identify technical architecture alternatives
   b. Specify required configuration categories
   c. Prepare program and project plans (e.g., work breakdown structure)
   d. Prepare subcontractor management plan
   e. Prepare risk management plan

The development and utilization of a management plan is the key to success of the SI program. Architectural and configuration alternatives must be examined and explicit program and project plans developed One of the most important activities to the success of development of life support systems is the identification and assessment of risk factors and the development of a successful risk management strategy. This includes assessment of technical and non-functional risk factors and the development of a risk management plan.

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5. Systems Design: Logical and physical design
    a. Design approaches (e.g., top-down, bottom-up, etc.)
    b. Use of CASE tools and other automated aids

As part of the design approach, a major activity is to define and explore all options that could meet the performance criteria established earlier. This may be accomplished in a top-down, bottom-up, or combination of these two approaches. Whichever approach is used, it is necessary to determine and analyze various options and alternatives that satisfy the performance criteria.

It is desirable to rate and weight the available options and alternatives, prior to making specific selections. It is the responsibility of the system integrator to apply the weightings to the separate performance characteristics of the most likely design configurations or the qualified responses to a request for proposal (RFP). These weights should have been established by the systems integrator in consultation with the client/sponsor, prior to design or solicitation through an RFP. It must be possible to demonstrate that the weights recommended by the systems integrator and approved by the client/sponsor are consistent with the importance of the functional requirements of the system. This is another way in which the audit trail that leads back to the functional performance requirements is maintained and utilized.
Several computer assisted systems engineering (CASE) tools may be used to facilitate these processes. These include Requirements Driven Design (RDD-100) from Ascent Logic, Software Requirements Methodology (SREM) from Alford, Requirements Traceability Manager (RTM) from Marconi Corp., and Planning and Design Methodology (PDM) from IBM.

6. Implementation: Design implementation, system tests, and operational deployment
    a. Identify Technical Configuration
    b. Specify required configuration component items
    c. Procurement from subcontractors
    d. Perform system tests
    e. System deployment

Select and deploy the preferred option(s). Included in this step are such widely diverse factors as insuring that non-operating questions such as operator training, systems shake-down and client/sponsor acceptance bench marking are addressed, and, in addition, insuring life-time system maintainability.

7. Evaluation: system review and plans for replacement/retirement
    a. Review and evaluate system functioning
    b. Obtain, install, test, and accept modified components
    c. Maintain, modify, augment and enhance systems
    d. Plan for system retirement/replacement.

Conduct various system performance tests and evaluate the outcomes based on client/sponsor requirements. Once the system has been deployed and is operational, it is necessary to conduct total system integration tests and evaluate the outcomes to ascertain that the functional and performance requirements have been met.

The phases in the system life cycle are interactive and iterative throughout the program

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development activity. Change management (and for life support systems change is inevitable) will involve the utilization of this same life cycle, thus it is prudent to have such a system in place from the onset of the program, as changes are a fact of life when dealing with life support systems. Some of the functional activities that are done by systems integrators during the course of the systems integration life cycle include:

1. Conduct general studies of needs to realize improved system performance;
2. Develop detailed specifications and designs;
3. Conduct risk studies and implement risk minimization strategies;
4. Perform system analysis and design;
5. Develop hardware and software design;
6. Employ project planning and control;
7. Perform business management and accounting;
8. Develop and nurture relationships with customers and subcontractors;
9. Develop hardware design and specification;
10. Carry out configuration management;
11. Accomplish testing;
12. Implement technology based solutions to business needs;
13. Train users of new systems; and
14. Develop a change management strategy.

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Biographical Sketch

James D. Palmer, Professor Emeritus, Information Technology and Engineering, George Mason University, received the BSEE in 1955 and an MSEE in 1957 from the University of California, Berkeley, CA and the PhD in Electrical Engineering in 1963 from the University of Oklahoma, Norman, OK. He has served as Professor of Electrical Engineering and Director of the School of Electrical Engineering of the University of Oklahoma, Professor of Electrical Engineering and Dean of Science and Engineering of Union College, Schenectady, NY and President of Metropolitan State College of Denver, Denver, CO. He was the founding Administrator (Assistant Secretary), Research and Special Programs Administration, the United States Department of Transportation. He served as Vice President of Research and Development, Mechanical Technology, Inc., Latham, NY and Executive Vice President, JJ Henry Co, New York and Moorestown, NJ. He was the first holder of the BDM International Chair in Information Technology at George Mason University where he held the positions of Associate Dean for Research and Graduate Studies, Acting Dean of the School of Information Technology and Engineering, and Chair, Systems Engineering Department. He has been co-author of three books and more than 100 papers in the areas of systems engineering, software systems engineering, and user needs and requirements. He received the degree Doctor of Public Service, *honoris causa*, from Regis University, Denver, CO. He is listed in many bibliographical reference works including Who's Who in America, American Men and Women of Science, and Who's Who in the West. He has received many honors including Outstanding Service Awards for contributions as President from the Systems Man, and Cybernetics (SMC) Society of the IEEE, the Joseph G. Wohl Outstanding Career Award from SMC, the Millennium Medal for Outstanding Achievements and Contributions from the IEEE, and the Outstanding Public Service Medal and Award from the United States Coast Guard for service as member and Chair of the United States Coast Guard Academy Advisory Committee (Board of Visitors).

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