System Integration Issues – Causes, Consequences & Mitigations

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Usually the systems integration in traditional designs is consistently underestimated. The increasing complexity of systems integration poses many challenges to system developers and integrators. During this phase, unexpected and unforeseen issues have rise. Most of these issues are inter organizations/ inter subsystems. When the project gets more complex, with more users, more suppliers, more processes within the company, and more functions and subsystems, the integration phase of the system becomes extremely difficult. System integration involves the combination of products from various sources / companies in a system – it means: interoperability, compatibility. The main purpose of this paper is to analyze the causes, consequences, and possible mitigations for issues found in systems integration.

Keywords - **System, integration, space, problems, mitigations**

I. INTRODUCTION

Chrissis, *et al.* [1] explain when the product/system integration is not executed correctly, that is, with problems, this usually means:

- The subsystems do not work together;
- The test time of integration increases;
- The integration environment is inadequate to support the integration activities and the
- The product is delivered without all of its components been tested.

The aim of this paper is to analyze the causes, consequences, and possible mitigations for problems found in systems integration.

It is considered primarily integration of space systems, the main focus of this work.

The background is the integration and testing activities developed at the Brazilian Institute for Space Research (INPE) - Integration and Testing Laboratory (LIT) – the most important satellite testing lab in the South Hemisphere.

The causes and consequences are divided into two major areas: management and technical and each one analyzed.

Finally, techno-management guidelines are proposed to mitigate problems in systems integration, as well as a check list to avoid the occurrence of these problems.

Section 2 presents system integration concepts and definitions; main inputs/outputs; and major activities.

Section 3 explains the main causes and consequences of system integration problems.

Section 4 presents guidelines to mitigate these problems.

Section 5 presents a brief summary of this research.

II. SYSTEM INTEGRATION

A. Concepts / Definitions

Grady [2] defines system integration as:

"A component of the system engineering process that unifies the product components and the process components into a whole.

It ensures that the hardware, software, and human system components will interact to achieve the system purpose or satisfy the customer's need".

NASA [3] introduced the concept of integration of space product / system as:

"The process used to transform the design solution definition into the desired end product of the WBS model through the assembly and integration of lower-level validated end products in a manner consistent with the product-line life-cycle phase exit that satisfies the criteria and design requirements definition solution."

That is, systems integration is a logical and objective procedure for applying in an organized and efficient way performance requirements for new and / or expanded project during acquisition, installation and operation of an operational configuration consisting of modules (or subsystems), each one of which may include restrictions or inherent limitations.

In order to implement this procedure, it is necessary to establish/define the inputs, outputs and the major activities that should be done.

B. Inputs

Overall entries for the integration of a system are:

i. Lowest level products within the system tree, which will be assembled and integrated.

ii. Documentation of specification, interface, etc.

iii. Implementation tools used to support the execution of the system integration activities.

C. Outputs

The system integration overall outputs are:

i. System / integrated product that meets the verification criteria.

ii. System documentation and manuals as defined by verification for acceptance of system/product, including: the integrated-systems or as-built system operation and maintenance manuals, if applicable.

iii. Documentation derived from the integration process, reports, records, etc.

D. Activities

The following activities are typical of the systems integration process:

i) To prepare the activities:

- To establish the integration strategy, integration sequence and procedures;

- To verify if the product configuration documentation is suitable to perform the system/product integration, within the whole life cycle.

ii) To receive the products / subsystems:

- Get all the products / subsystems required to assemble and integrate the desired system.

- Confirm that the products / subsystems received and to be integrated have been validated to demonstrate that they meet the subsystems requirements, including interfaces requirements.

iii) To prepare the test implementation tools.

Prepare the integration environment in which the assembly and integration will be accomplished including test facilities, test tool, and test team.

iv) To perform the assembly, integration and test of the system.

Assemble, integrate, and test the products / subsystems received to get the product / system desired in accordance with specified requirements, configuration documentation, interface requirements, rules, and procedures.

v) To prepare System Verification / Validation documentation

Prepare test reports, inspection reports, review documentation, etc. necessary to achieve compliance of the system, including operating manuals, maintenance, etc.

A typical flow diagram (adapted IDEF0) of the product / system integration process is provided in Fig. 1 with inputs, outputs and key activities.

III. CAUSES & CONSEQUENCES OF PROBLEMS IN SYSTEMS INTEGRATION

Multifaceted are the causes of problems and their consequences found during the process of systems integration. We can group them in management and technical, as explained in the following items:

A. Management

i. Poor Configuration Management.

It is of relevant importance the problem of configuration management during the process of integration and testing.

When hundreds or thousands of engineers are working on a product / system, usually one of them is really busy in identifying and implementing changes and not in controlling of their impact on the overall process of integration.

Strict procedures for controlling changes in integration settings can reduce the problem of management, but this often conflicts with the need to solve problems quickly during integration.

ii. Establishment of a inadequate testing philosophy.

The definition by the project management of a poor testing strategy in terms of testing development models, leads to significantly increasing the technical and schedule risk for the system integration activities.

iii. Improper organization and assignment of responsibilities.

Poor structuring and training of staff involved in system integration leads to serious problems in coordination, control and execution of integration activities.

iv. Deficient interrelationships of AIT in the project development.

Participation, sometimes minimal, of AIT in the design and specification of the product/system makes that AIT requirement not adequately taken into account in system design, resulting in an integration process technically not optimized.

v. Test strategy and integration plan is not developed in time.

To start system integration with the absence of an integration strategy already validated and consolidated, and without an integration plan that includes all activities to be performed is a high risk factor for not developing optimized system integration.

Test plans developed just before the start of system integration impacts on the preparation and development of the test tool and test infra-structure required for the execution of all tests; in addition test procedures do not contemplate the verification of all specifications.

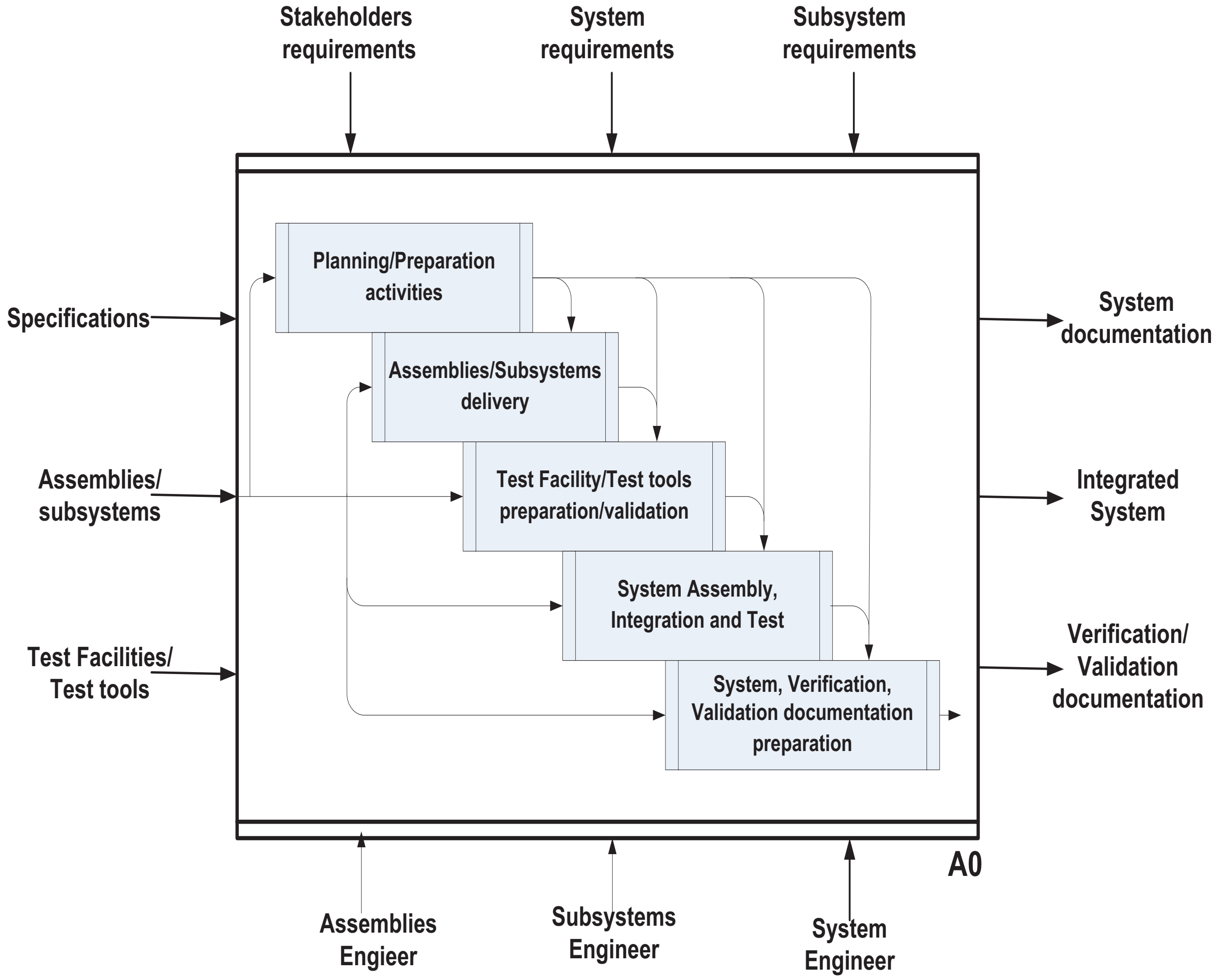

Fig. 1 System integration process generic flowchart.

vi. Test tools and test infrastructure not available for system tests.

Due to poor planning, the validation of test tools test just after the start of the tests contributes to a problematic system test campaign.

vii. Insufficient time for testing.

You can have a good test plan, a good test infrastructure, an adequate test team, but if the time allotted for the activities is unrealistic, this is a critical factor for execution of the integration process, with high risk of occurring problems during the integration, as well as poor identification of potential system failures.

B. Technical

i. Maturity of processes.

Processes that have a high maturity or widely validated in the process of integration are sometimes not properly implemented within the project.

ii. Incomplete requirements.

Completeness of the requirements is especially difficult to achieve if not yet mature technologies should be introduced into the system, because of little experience with these technologies.

Practice shows that obtaining a set of requirements "baselined" at the beginning of system development is a process that takes time, effort and money.

Another aspect is the modification of the requirements, which has significant impacts on the preparation and implementation of systems integration, as well as the situation of having excessively stringent requirements, bringing major problems during integration and testing at the system level.

iii. Development of testing software.

Testing software poorly developed very close to the beginning of integration at the system level, brings high risks to implementation and control of system tests.

iv. Deficient test tools at subsystem level.

The absence of appropriate tests tools for qualification tests at subsystem level leads to various problems that are often only identified and quantified at the system level, during system integration.

v. Lack of standardization of engineering data.

Not using common technical standards between the various teams involved in the project, from development through the system integration sometimes leads to misinterpretation of data, especially the interface data.

vi. Deficient Project design.

A significant portion of problems in system integration can be traced to deficiencies in system design, such as unexpected interference between subsystem / units, complex simultaneous interactions.

These problems often have their origin in the system requirements and design, which often become visible only during integration.

vii. Use of technology that requires complex integration project.

The use of technologies for units and / or subsystems manufacturing that require very complex hardware or software for verification during the process of integration at the system level, leading to substantial increase of risk during the verification.

IV. GUIDELINES FOR MINIMIZING PROBLEMS IN SYSTEMS INTEGRATION

A. General Considerations

Current industrial practices show that the main effort of system development is shifting from the design and implementation to the phase of integration and system testing [4].

Also, to find and fix problems during integration and testing can be up to 100 times more expensive than finding and correcting problems during the stages of definition / requirements analysis and design.

Software intensive organizations such as IBM claim that "debugging, testing, verification and can easily range from 50 to 75 percent of the total development cost." [5].

In terms of space systems:

- The costs of integration and testing (AIT) account for 15% of the total project [6] and,
- The average time currently allocated to AIT is 25% of the total spent on project execution [7].

Therefore it is very important to minimize the occurrence of these problems for better system development.

Next section presents a set of guidelines to mitigate, minimize problems that may occur during integration and system tests, in particular those set forth in the preceding sections.

B. Technical-Management Guidelines to Mitigate Problems in System Integration

The following guidelines aim to minimize and / or eliminate many common problems that occur during the process of systems integration:

i. Structure a team composed of senior researchers and technicians in order to:
   - Identify and analyze recurring problems of high impact, their contexts and their early warning signs.
   - Capturing the best organizational practices and techniques and provide practical recommendations.
   - Develop a plan to make this information easily known to project management and technical personnel throughout the system development community.

ii. Identify the subsystems critical interfaces which are subject to change due to its dependence on a rapidly technology changing. These interfaces are likely to have frequent changes in requirements, which in turn will bring impact on tests.

iii. Use a modular design approach, combining well-defined interfaces between the modules / subsystems, in order to isolate the effects of changes in the system, and facilitates the testing at the level of unit / subsystem.

iv. Verify all performance requirements and re-evaluate their need. Relocate the requirements as possible to allow a wide use of open standards throughout the system.

v. Define a strategy for the management of test data:
   - What are the data elements that should be collected and how, when and why they are needed;
   - What tools are being used to share and use such data between all those involved in the process of integration and testing.

vi. Establish a comprehensive list of required documentation to support the planning and execution of integration activities and tests.

vii. Maximize use of qualified components, subsystems and test equipment support.

viii. Invest in resources that facilitate testing and/or simulate parts of the system not yet integrated.

ix. Conduct subsystem interface compatibility checks, preferably during development.

x. Plan rigorous verification tests of all ground test equipment well before the acceptance tests of the system.

xi. Plan an orderly and disciplined process of tracking identification and resolution of anomaly.

xii. Promote involvement of the assembly, integration and testing (AIT) needs and requirements in the early stages of project development, so that:
- The integration and testing effort is spread over a broader framework of project time, which in turn reduces the effort being invested in the process of integration and testing itself;
- Secondly, it allows earlier (and therefore cheaper) detection and prevention of problems that occur during real integration, which also increases the quality of the system.

xiii. Implement a flexible management of activities involving staff, equipment and testing facilities.

xiv. Conduct training, in advance, of the test team.

xv. Arrange the test documentation properly matching to the program requirements.

xvi. Establish a testing methodology in order to make early preparation of the tests - procedures / testing tools.

xvii. Staffing subsystem support during the execution of tests at the system level.

V. CONCLUSIONS

Improving of the developing process of a system is a recurring theme of research, particularly by INCOSE [8].

However much of the research in this area is focused on improving the requirements analysis, design and manufacturing phases of system development, little attention is given to the system integration and test phase.

In most cases, research in systems engineering describe procedures and guidelines for system development, and minimally involve the system integration and testing.

The system integration issues analysis and the guidelines for minimizing the problems during integration described in this paper therefore belong to this context.

This paper contributes to improve the execution of the system integration activities and reflects the lessons learned during the execution of the Satellite AIT activities at LIT, on Brazilian satellites (SCD1/SCD2A) as well as in international satellites(CBERS FM2, CBERS FM2B), successfully launched.

This improvement process is in constant evolution and reflects the experience mentioned above as well as the permanent exchange with space agencies and international institutions.

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