

An Integrated Approach for Systems Engineering and Project Management Applied to the Implantation of a Satellite Test Laboratory Infrastructure

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Abstract— *The objective of this article is to describe a management model applied to the development of an executive project and implantation of a large infrastructure for space activities using the systems engineering and project management concepts integrated. The concepts used aimed to improve the planning, execution and management of processes related to the infrastructure life cycle to be implemented for the development of activities in the space sector for assembly, integration and tests for large satellites at INPE, Brazil*

Keywords—*Systems Engineering, Project Management, Integrated Approach.*

I. INTRODUCTION

The implementation of projects for large spacial infrastructures is always a challenge, due to the complexity of the requirements, definition of technical solutions and high level of administrative and managerial demands in order to achieve a successful implantation.

The organizations which operate space infrastructures do not usually design and construct the installations themselves, this is done by third party contractors through several different purchase agreements.

The complexity of multidisciplinary projects and technical and administrative procedures requires many specialties and disciplines to be applied together. In spacial infrastructure projects, the concepts of systems engineering (SE) are widely used, considering the complexity of the installations and equipment to be implanted.

Nowadays most part of projects in technical fields utilize the concepts of project management (PM) to complete projects as planned, mainly on the aspects of cost, quality and time.

When studying PM and SE separately and making a comparison between both, we can find overlaps between these two solid disciplines. This article relates the experience of combining both fields of PM and SE to achieve an implantation of a laboratory infrastructure expansion according to the requirements and exigencies of cost, time and quality.

Despite the large impact that a large space infrastructure implantation has on the results of space system projects,

the vast majority of current literature addresses the issue marginally, with greater emphasis on the development of the space segment products.

The expansion project of the Integration and Testing Laboratory for satellites on the Brazilian National Institute of Spatial Research (INPE), involving the executive project, the execution of the physical facilities (construction of the buildings) and the utilities installation (energy, fluids, air conditioning, etc.) to permit the installation of systems to manipulation, assembly, integration and testing (functional and climatic) of large satellites or their subsystems is a complex project that has benefited from an integrated systemic approach from the beginning of its deployment to the current phase.

The use of SE and PM concepts in complex projects is a common practice in the professional community that operates in the project implementation segment. A joint research promoted by PMI and INCOSE and published by Conforto et al. (2013) shows, according to their results illustrated in figure 1, the percentages of use of the concepts of Systems Engineering and Project Management by program managers and chief systems engineers often involved in this type of project. While approximately 55% of systems engineering chiefs use ES concepts and 20% use PM concepts, program managers have an inverse proportion, with 13% using ES concepts and 58% using PM concepts.

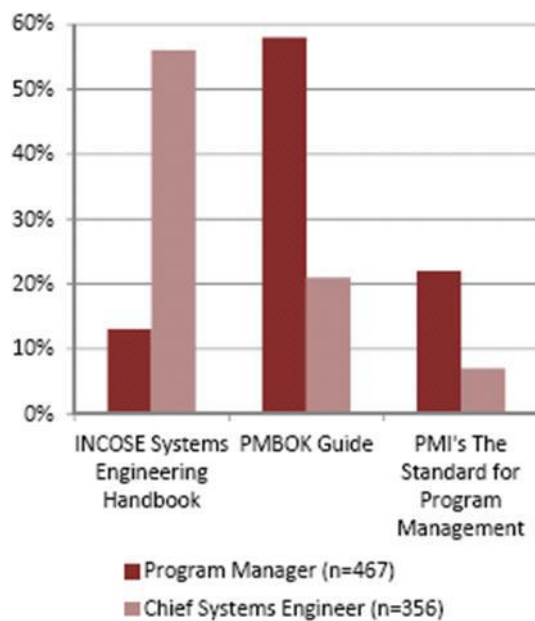


Fig. 1: Use of INCOSE and PMI standards by Systems Engineering and Project Management professionals [Conforto et al. 2013].

II. SYSTEMS ENGINEERING APPROACH

Systems Engineering is a collaborative multidisciplinary engineering approach to develop, follow up and verify a life-cycle balanced system solution that meets stakeholder expectations (LOUREIRO, 1999).

Systems Engineering has its main focus on defining the needs and required functionality of customers in the early stages of the development cycle, with emphasis on formalization and registration of these requirements, and then to proceed with the design synthesis and system validation, considering all aspects of the system: operations, cost, schedule, performance, testing, fabrication, training, support and disposal. Systems engineering considers the business aspects and technical needs of all customers in order to offer a quality product that meets the user's needs. (INCOSE 2004).

According to NASA's Handbook, which is one of the models for using Systems Engineering concepts for space projects, project management consists of three main objectives: managing the project team, managing the technical aspects of the project and managing the project cost & schedule. As shown in Figure 2, these three functions are interrelated and complementary.

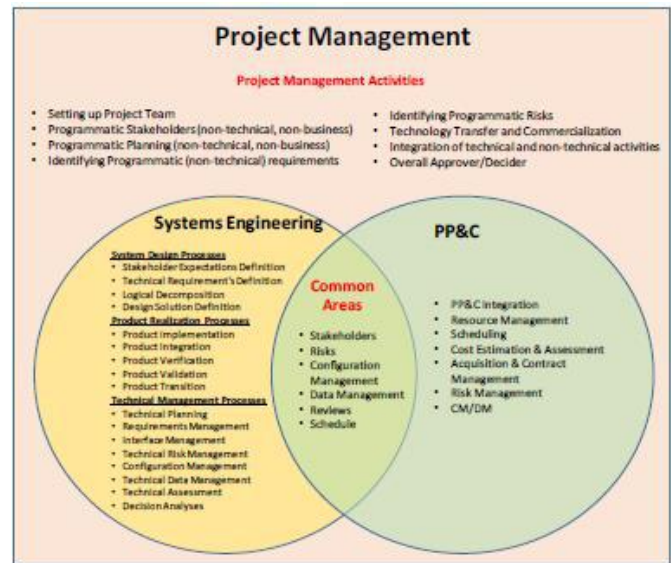


Fig. 2: SE as context of Overall Project Management [NASA SE Handbook 2017, fig. 2.0-1].

According to Fig. 3 (NASANPR 7123.1B, 2013), systems engineering requires a systematic and disciplined set of processes that are recursively and iteratively applied to design, development, operation, maintenance and closure of systems, throughout overall programs and projects lifecycle.

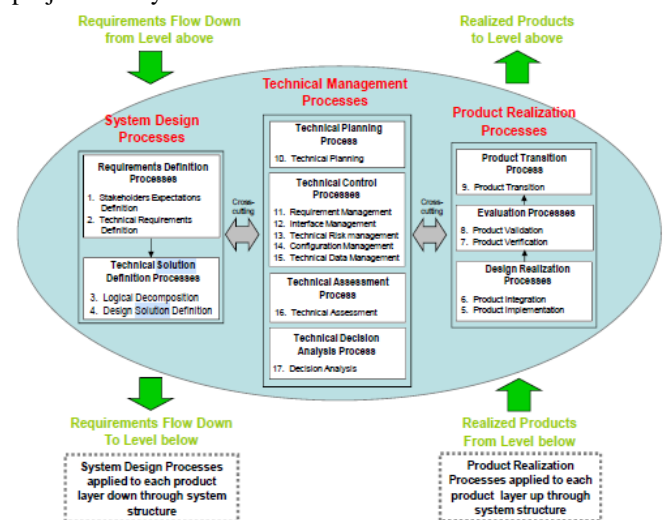


Fig. 3: SE engine [NASA NPR 7123.1B-, 2013, fig. 3-1].

As shown in Fig. 3, the evolution of systems design and product execution processes are supported by the technical project management process. In the case of space products, often all activities represented in the diagram are performed by professionals with a background in systems engineering, due to the particularities of the final product. When the system under development is an infrastructure for the space sector, there are design and implantation specificities that complement the requirements of the activities or systems which will be operated in the

infrastructure, often extrapolating the experience and specific technical knowledge of the system engineers involved in the project.

The systems engineering approach in the management of the technical aspects of the project, with emphasis on the definition of technical requirements and the definition of the project solutions is extremely useful in the requirements definition and executive project development phases of an infrastructure implantation for space segment projects.

III. PROJECT MANAGEMENT APPROACH

We can define Project Management (PM) as a multidisciplinary approach consisting of a set of management processes, focusing on the definition of resources, planning and control of activities aiming the successful implementation of projects, achieving all the project requirements.

As projects evolve in complexity and importance, a segment of the professional community associated on the Project Management Institute (PMI) and involved in project management has identified best management practices and recorded this information in the PMBOK (Project Management Body of Knowledge) guide, designed to develop and disseminate project management best practices that are widely accepted in professional and academic circles. As per PMBOK best practices, project management is divided into five process groups:

- Initiating
- Planning
- Executing
- Monitoring and Controlling
- Closing

As shown in Figure 4, the integrative nature of project management requires interaction between its process groups for the correct evolution of projects.

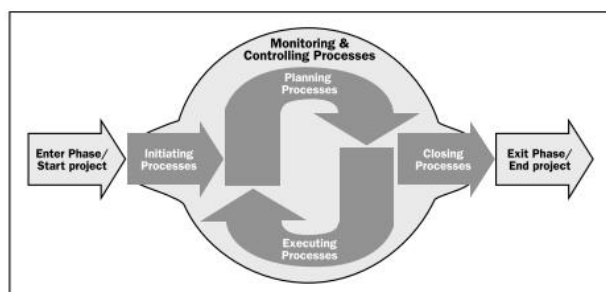


Fig. 4: Project Management Process Groups
[PMBOK,2008, fig. 3-1].

According PMBOK, to be an efficient Project Manager, one requires flexibility, good judgement, strong leadership, negotiating skills and a solid knowledge of project management practices. The project team is a group of

professionals involved with management of the project and individuals with knowledge of the particularities of the installation or characteristics of the equipment and activities which will be performed on the facility.

PMBOK divides project management into ten knowledge areas, each of them containing the five process groups and their recommended processes.

Considering PMBOK's recommendations that process selection for each project should be tailored for the project's characteristics, an illustrative example of project management process for a large space infrastructure is shown in table 1.

Table 1: Project Management Process Groups and Knowledge Areas Mapping tailored for a specific project

KNOWLEDGE AREAS	ACTIVITIES BY PROJECT MANAGEMENT PROCESS GROUPS		
	Planning Process Group	Executing Process Group	Monitoring & Controlling Process Group
6. Project Schedule Management	6.1 Plan Schedule Management 6.2 Define Activities 6.3 Sequence Activities 6.4 Estimate Activities Durations 6.5 Develop Schedule		6.6 Control Schedule
7. Project Cost Management	7.1 Plan Costs Management 7.2 Estimate Costs 7.3 Determine Budget		7.4 Control Costs
9. Project Resources Management	9.1 Plan Resources Management 9.2 Estimate Activities Resources	9.3 Acquire Resources 9.4 Develop Project Team 9.5 Manage Team Project	9.6 Control Resources
12. Project Procurement Management	12.1 Plan Procurement Management	12.2 Conduct Procurements	12.3 Control Procurements

[based on PMBOK,2017, table 3.1].

IV. INTEGRATED MANAGEMENT APPROACH

The objective of the expansion project of INPE's Integration and Testing Laboratory for satellites is to increase the capacity for manipulation, assembly, integration, and functional & environmental testing of large satellites (telecommunications class) and their subsystems in its various stages of integration. This article reports the main aspects of the approach used in the first phase of the expansion project, which includes the elaboration of the complete executive project, the construction of the Area 2, destined to the implantation of the testing equipment and its utilities. In Figure 5 we can see the representation of the current laboratory layout and the two areas covered by the expansion project (Area 1 and Area 2).

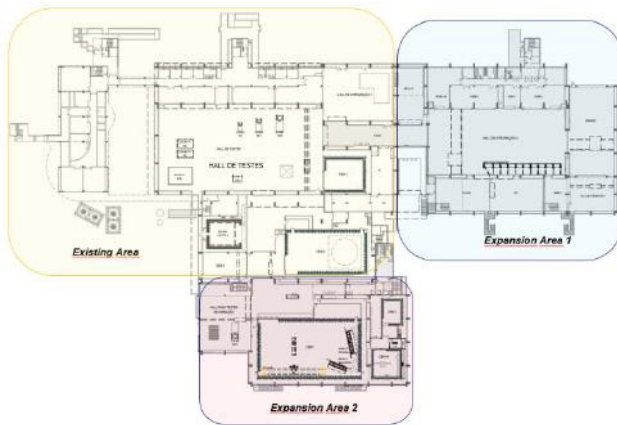


Fig. 5: LIT expansion project layout including new areas 1 and 2.

According to Ermes et al (2012), Project Management and Systems Engineering are highly overlapping endeavors and, while the SE has the primary responsibility of ensuring the quality and performance level of the deliverables, PM is responsible for ensuring that the project is completed in conformity with cost and schedule, following the quality requirements.

In infrastructure projects implantation, activities are often divided into two distinct phases: the design phase and the construction phase. According Sharon et al (2010), the technical issues are related to the product domain and the managerial aspects are related to the project domain. In the design phase, we are in the product domain and the main activity to be developed by the technical team is to define the requirements and functionalities desired for the installation. In this phase it is necessary to define the equipment which will be installed in the infrastructure, even preliminary, to avoid missing the necessary interfaces between the operational equipment installation and infrastructure utilities. In the construction phase we are in the project domain and the main activities are related to the management of the project evolution, making sure the targets established are met.

To compose a team for managing a complex project, Eisner [2013] proposes an organization chart consisting of three main roles: the Project Manager (PM), a Chief Systems Engineer (CSE) and a Project Controller (PC). According to Eisner, the CSE is responsible for the systems integrity of the overall system. The PC is responsible for scheduling, costing, resource assignments, facilities and contract related activities. All activities are coordinated by the PM.

According to the European Cooperation for Space Standardization [ECSS 2009], in its ECSS-M-ST-10 standard, project implementation activities can be carried out by a single project group, composed by a group of

specialists who master all the project disciplines or, more often, by a project group that serves the core operational activities, complemented by the support of an outside staff or technical experts for other specialties not covered by the project team.

To implement the INPE's laboratory expansion project, the project team was established including members of the laboratory test operational teams whose main profile is systems engineering with knowledge on the equipment and operations to be performed in the new installation and members of the engineering group, specialists with extensive experience in Project Management, including the elaboration of procurement public processes, infrastructure project and building works management. Figure 6 represents the organization chart established for the LIT expansion project.

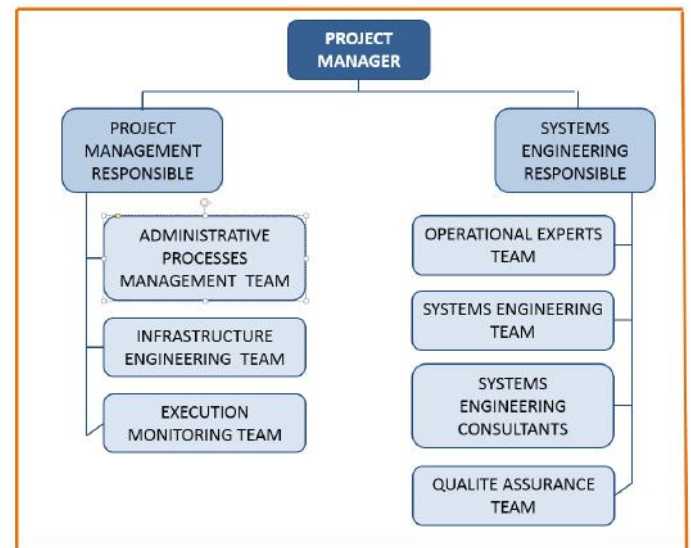


Fig. 6: LIT laboratory extension project group organizational chart.

According to the Guide for the Application of Systems Engineering in Large Infrastructure Projects from INCOSE (2012), large infrastructures projects are composed by the lifecycle indicated in fig. 7, and the activities can be classified in two main stages: the development of an engineering solution in the form of a detailed design (executive project) and the execution of the solution by procuring contractors to build the solution.

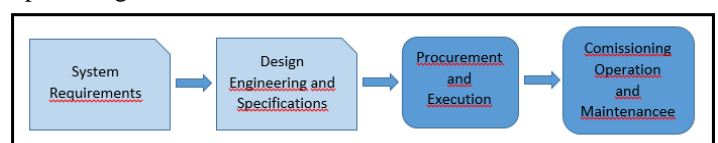


Fig. 7: Traditional Lifecycle for Large Infrastructure Projects [based on INCOSE-TP-2010-007-01, 2012, fig. 2.1].

In the LIT expansion project, the technical requirements of the equipment to be installed, its interfaces with the building, utilities and its conditions for installation and operation were conducted by team members with knowledge in systems engineering, coordinated by the "Systems Engineering Responsible". Specialists of the laboratory also participated actively in these activities, as well as national and international consultancies specialized in activities for the space segment.

The main equipment to be installed in the New Area 2, as illustrated in figure 8, is specifically designed to perform sophisticated and high precision tests. This equipment's performance is sensitive and can be strongly impacted by civil works and utilities interfaces.

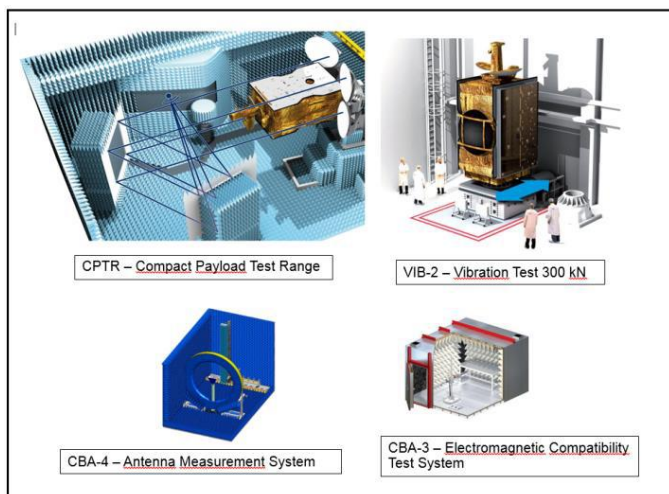


Fig. 8: Illustration of the main equipment to be installed.

The executive project of utilities and the introduction of the functional aspects of installation for areas such as maintenance, administration and technical operational support were defined in majority by the technical team of engineers with experience in implementation and monitoring of execution works. The definition of the scope of services to be contracted and material purchasing, the management of the delivery schedules of goods and services, the quality of the work execution and the acquisitions process were performed by the team members who presented project management profile, coordinated by the "Project Management Responsible".

The first phase of the project, including the elaboration of the complete executive project, the execution of the civil works and installation of utilities, was budgeted at around US\$ 10 million. We can see in figure 9 images with the chronology of the evolution of the civil works. The works were executed in accordance with the scope, costs and schedule defined for this phase.



Fig. 9: Evolution of the works on LIT laboratory extension project.

V. CONCLUSION

The methodology used in the development of LIT expansion project activities sought to integrate the concepts of development and management of space systems advocated by the System Engineering discipline to the aspects of organization and management of large projects disseminated by the Project Management discipline.

The project was developed in its initial phase through one of the pillars of the systems engineering discipline, which is the definition of requirements, by the initial identification of a problem to be solved and the subsequent definition of the needs of the system to be developed.

The systems engineering team, by analyzing the activities to be developed in the infrastructure and the characteristics of the test equipment needed to perform these activities, elaborated the technical requirements that the infrastructure should meet for these needs. These requirements guided the definition of the infrastructure areas and volumes, as well as the fundamental utility characteristics (electricity, hydraulic, air conditioning) for the test equipment.

The infrastructure engineering team, through the analysis of operational support activities such as administration, maintenance, cleaning, surveillance and security, elaborated the technical requirements that the infrastructure should meet for these needs. These requirements complemented the guidelines for preparing the infrastructure layout, as well as complementing and consolidating the fundamental characteristics of utilities with the administrative needs of IT, access control and asset security surveillance.

Upon completion of the requirements definition and registration in the technical specification documents of the services, the administrative processes group elaborated the procurement processes, complementing the technical specifications with the technical requirements for suppliers

qualification of project, execution, supply of materials and equipment, observing the legal requirements for contracting these services, following the procedures which are mandatory for a project financed by public resources. The integrated approach used serves as a reference for future projects for the implementation of large space system infrastructures that may be implemented by similar institutions, as well as the basis and inspiration for further complementary studies aiming at the development of the integration theme between Systems Engineering and Project Management applied to the development of complex projects.

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