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ENGENHARIAS:

Metodologias e Práticas de Caráter Multidisciplinar

2

Henrique Ajuz Holzmann
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Atena Editora
Ponta Grossa – Paraná – Brasil
Telefone: +55 (42) 3323-5493
www.atenaeditora.com.br
contato@atenaeditora.com.br

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APRESENTAÇÃO

Um dos grandes desafios enfrentados atualmente pelos engenheiros nos mais diversos ramos do conhecimento, é de saber ser multidisciplinar, aliando conceitos de diversas áreas. Hoje exige-se que os profissionais saibam transitar entres os conceitos e práticas, tendo um viés humano e técnico.

Neste sentido este livro traz capítulos ligados a teoria e prática em um caráter multidisciplinar, apresentando de maneira clara e lógica conceitos pertinentes aos profissionais das mais diversas áreas do saber.

Para isso o mesmo foi dividido em dois volumes, sendo que o volume 1 apresenta temas relacionados a área de engenharia mecânica, química e materiais, dando um viés onde se faz necessária a melhoria continua em processos, projetos e na gestão geral no setor fabril.

Já o volume 2 traz, temas correlacionados a engenharia civil e de minas, apresentando estudos sobre os solos e obtenção de minérios brutos, bem como o estudo de construções civis e suas patologias, estando diretamente ligadas ao impacto ambiental causado e ao reaproveitamento dos resíduos da construção.

De abordagem objetiva, a obra se mostra de grande relevância para graduandos, alunos de pós-graduação, docentes e profissionais, apresentando temáticas e metodologias diversificadas, em situações reais.

Aos autores, agradecemos pela confiança e espirito de parceria.

Boa leitura

Henrique Ajuz Holzmann
João Dallamuta

SUMÁRIO

CAPÍTULO 18

SYSTEMS CONCURRENT ENGINEERING TECHNIQUES APPLIED TO MAP AND TO MONITOR BRAZILIAN SHORE CORAL REEF BY USING A SATELLITE MISSION

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Isomar Lima da Silva
Space Engineering and Technology - National Institute of Space Research-INPE, São José dos Campos - SP, Brazil
http://lattes.cnpq.br/2850176208849053

Geilson Loureiro
Space Engineering and Technology - National Institute of Space Research-INPE, São José dos Campos - SP, Brazil
http://lattes.cnpq.br/7824447045520901

José Wagner da Silva
Space Engineering and Technology - National Institute of Space Research-INPE, São José dos Campos - SP, Brazil
http://lattes.cnpq.br/5174955988023130

Andreia Sorice Genaro
Space Engineering and Technology - National Institute of Space Research-INPE, São José dos Campos - SP, Brazil
http://lattes.cnpq.br/1326926734177295

Samara de Toledo Damião
Student in Space Engineering and Technology - National Institute of Space Research-INPE, São José dos Campos - SP, Brazil
http://lattes.cnpq.br/6103213814018736

ABSTRACT: This work aims to demonstrate how the Systems Concurrent Engineering (SCE) process and its multidisciplinary collaborative techniques can be used in the development of a satellite mission to map and monitor coral reefs in the Brazilian coast. For that, a simultaneous product development approach will be used with the aim to derive, develop and validate a balanced solution during the product life cycle that satisfies the stakeholder's expectations. This approach was chosen due to the development target product having a complex nature, needing clarity in the definition of user's necessities, required functionalities, systematic documentation of the requirements and validation considering the whole problem. The application of systems engineering in this work comes from stakeholder analysis, requirements analysis, functional analysis, system architecture, detailed design and other aspects related to the used approach. The simultaneous engineering approach of systems has proved to be very effective during the development of complex systems. Its application in the life cycle of CoralSat project allows a glimplse of problems of the solutions during the life cycle (development). The processes of SCE made possible the modeling of CoralSat system since its initial stage with the mission analysis of the product and organization, until its finalization, always seeking to attend the stakeholders needs, being this system ready for the point of view of the operation of the requirements.

KEYWORDS: Systems engineering, Mapping, Satellite, Coral Reefs, Stakeholder.

TÉCNICAS DE ENGENHARIA SIMULTÂNEA DE SISTEMAS APLICADAS PARA MAPEAR E MONITORAR O RECIFE DE CORAL DA COSTA BRASILEIRA USANDO UMA MISSÃO DE SATÉLITE

RESUMO: Este trabalho tem como objetivo demonstrar como o processo de Engenharia Concorrente de Sistemas (SCE) e suas técnicas colaborativas multidisciplinares podem ser utilizadas no desenvolvimento de uma missão de satélite para mapear e monitorar os recifes de coral no litoral brasileiro. Para isso, será usada uma abordagem simultânea de desenvolvimento de produto com o objetivo de obter, desenvolver e validar uma solução equilibrada durante o ciclo de vida do produto que atenda às expectativas das partes interessadas. Essa abordagem foi escolhida devido ao produto-alvo de desenvolvimento ter uma natureza complexa, necessitando de clareza na definição de necessidades do usuário, funcionalidades necessárias, documentação sistemática dos requisitos e validação considerando todo o problema. A aplicação da engenharia de sistemas neste trabalho vem da análise das partes interessadas, análise de requisitos, análise funcional, arquitetura do sistema, projeto detalhado e outros aspectos relacionados à abordagem utilizada. A abordagem de engenharia simultânea de sistemas provou ser muito eficaz durante o desenvolvimento de sistemas complexos. Sua aplicação no ciclo de vida do projeto CoralSat permite vislumbrar problemas das soluções durante o ciclo de vida (desenvolvimento). Os processos da SCE possibilitaram a modelagem do sistema CoralSat desde seu estágio inicial, com a análise da missão do produto e organização, até sua finalização, buscando sempre atender às necessidades das partes interessadas, estando este sistema pronto para o ponto de vista da operação do os requisitos.

PALAVRAS-CHAVE: Engenharia de sistemas, Mapeamento, Satélite, Recifes de Coral, Stakeholder.

1 | INTRODUCTION

Systems engineering is the multidisciplinary and collaborative approach which requires an holistic vision, from the initial through the last one phase of life cycle product, with the multidisciplinary engineering which contributes to the derivation of a balanced solution over the life cycle attending the expectations of all stakeholders and shareholders, Loureiro (1999). The systems engineering process, runs along the cycle, are composed by three stages of a system solution: derivation, evolution and systemic solution verification. From the need statement expression so far the product acceptance and readiness for use, operate and than disposal phase, Loureiro (1999),

For Fulundi (2011), systems engineering is an interdisciplinary approach that, through collaboration, turns possible the implementation of highly complex systems. In addition to serve as an integrator of different specialties knowledge focusing on team effort, the systems Engineering provides the management of several stakeholder interests considering both the business and technical needs of all customers. The goal is to provide a high quality product that meets the customer needs who will be benefit with a product resulting from a complex project, Fulundi (2011). Into the space sector, the products usually derive from complex projects that requires high quality and reliability, and these characteristics justify the use of a multidisciplinary and collaborative engineering approach in the projects or missions to reach all stakeholders.

The demonstration of systems engineering application techniques in the design and development of lifecycle processes to a satellite mission to map and to monitor the reef coast of Brazilian coral is the main objective in this paper.

The motivation to choose the application of a satellite mission for the mapping of coral reefs is due to the constant urbanization of the Brazilian coastal area, in this way the coral biome has been affected over the last decades. Another cause identified is the pollution and disturbance arising from the shore occupation, in other words, the coral health has been declining and its degradation can be captured using technologies. The whitening of the corals indicating the beginning of their life declining, coral death affects the ecosystem of which it is composed, also makes navigate more dfficult, and its hardened carcass may cause serious damage to the hull of vessels.

It is because all of these problems that the need for a constant verification of the coastal region becomes imperative and to meet this need the CoralSat satellite was developed.

The coastal strip of Brazil has more than 8.5 thousand kilometers in length and until today there is none constant and effective mapping and monitoring of coral reefs as what can be done by satellite equipment as CoralSat can perform.

That said, this article is based on the systems concurrent engineering method developed by Loureiro (1999), which proposes the product and the organizations simultaneously development and implementation into the product life cycle in the course of Simultaneous Systems Engineering processes.

Using the systems engineering approach and tools, the scenarios proposed in the CoralSat design were divided into six parts (Mission, Life Cycle, Stakeholder Analysis, Requirements, Functions e Architecture) thus enabling a clear layout of the system parts and their respective purposes.

The work that follows present the effort of a Systems Concurrent Engineering analysis on CoralSat mission and its life-cycle analysis considering product and organisation. The chosen operation scenario aforementioned as example is: Sensing. During this scenario, the CoralSat receives data from ground station; processes, treats and stores data; sends data to the ground station.

This paper structure this Introduction containing this paper objective; 2. Systems Concurrent Engineering references and methods; section 3. CoralSat mission analysis and description; section 4. Stakeholders, Requirements, Functional analysis, Architecture and Design are described considering Sensing of CoralSat as an operational scenario example; section 5. Mission discussion exploring the work results significance; and section 6. The main study conclusion.

2 I REFERENCES AND METHODS

2.1 Systems Engineering

Described as a multidisciplinary approach collaborative of engineer to derive, develop and verify a balanced solution throughout the life cycle and that meets the expectations of the stakeholders, INCOSE (2015), System Engineering can also be seen as:

- An engineering approach;

- Applicable to the development of complex products.

In the space area, it is used in the development of products from set of gears to satellites to control the Earth's orbit, as a basis for the requirements established by the stakeholders, Stevens (1998).

2.2 Stakeholders

Stakeholders are individuals and organizations actively involved in the project or whose interests may be affected as a result of project execution or termination, INCOSE (2015) and Genaro et al. (2014).

For PMBOK, Stakeholders can be viewed as "an individual, group, or organization that may affect, be affected, or be affected by a decision, activity, or a project outcome," PMI (2017). It can be considered as stakeholders from the members of the project developer team, sponsor, suppliers, company owners, external public (customers) among other stakeholders depending on the type of project in question.

2.3 Requirements analysis

For Loureiro (2010), the requirements analysis is to systematize the process of defining the requirements, obtaining a correct and complete specification of the same for elaboration of the Requirements Document, as the process of acquisition, refinement and verification of the stakeholders needs.

Requirements Analysis can be seen as the initial contact between the developers and the buyers of the project, it is considered the activity "what the system should do and not how it will be implemented", PMI (2017).

2.4 Functional Requirements

Functional requirements are functional statements of how the system should react to specific inputs and how it should behave in certain situations where there is interaction between the system and its environment. They can also explicitly state what the system should not do; the specification must be complete and consistent according to Loureiro (2010). This specification comes with the \functional analysis being performed simultaneously for the elements of the product and the organization". In this way, an essential functional architecture is derived and other nonfunctional requirements are captured, an allocable functional architecture is obtained from the iterative partitioning and from the essential functional architecture grouping Loureiro (2010).

2.5 Method

2.5.1 Use of Systems Engineering

As part of the CoralSat development method, we initially sought to identify all the tasks that should be performed by defining them in order to be performed throughout the development cycle.

The identified activities were grouped in stages or in phases to enable management and verification following verification criteria established by the Stakeholders at the beginning of the project. From this phase, the application of the systems engineering approach began, aiming to join in a development effort with those involved in all areas relevant to the project.

The mission statement was initially made, followed by the product life cycle processes definition, and the start of the scenario definition, from these steps the processes for CoralSat system architecture development began.

For the product and system organization elements, the simultaneous development approach was used where stakeholder analysis, requirements analysis, functional analysis and implementation were done resulting in system requirements, functional architecture and implementation architecture executed at the same time INCOSE (2015).

The systems concurrent engineering development approach allowed a better management of the tasks inserted in each development phase. This approach enabled the team to have a macro view of the Coral-Sat project life cycle, and thus subdivide the phases into tasks or even sub-phases or sub-tasks, which facilitated the mission systemic development in all stages of processes execution from conception to disposal.

The product life cycle processes requirements were considered since the beginning of development, so many times it was possible to anticipate requirements, and thus reduce the risk of changes that could occur during the project development.

2.5.2 Stakeholders needs

The application of Systems Engineering approach to develop CoralSat satellite mission and the choice to carry out this study was based on the needs observed by the main project Stakeholders: Brazilian Navy, researchers from IBAMA, Environmental Organizations and INPE.

One of the points most emphasized by the environmental area Stakeholders was the occurrence of degradation of the coral reefs of the Brazilian coast due to bleaching. In its technical language, "bleaching is the death of the polyps, this is caused by the destruction of the zooxanthellae, unicellular algae that live within the celery of the polyps and provide them with part of the necessary food, through photosynthesis, or by plankton reduction", Luiz (2018). From that point on, Stakeholders needed a system capable of mapping Coral

Reefs, and collecting data on their growth and degradation, identifying the whiteness that has arisen with much frequency.

As a requirement, the stakeholders needed accurate and continuous images of coral reefs generated by CoralSat, the design was de_ned following an image accuracy of 0.5m minimum and a data precision of 96%, the spectral wavelength ranges from 310 nm to 750 nm with an error of +/- 15%. The images capture cycle at the same point every 26 days, and the data transmission being performed to the CoralSat Operation Center within 24 hours after the capture.

When Center of Operation Control CoralSat receives the data, the responsible team analyzes quality data and then release and disclosure to the “Stakeholders - Brazilian Navy, researchers from IBAMA, Environmental Organizations and INPE.”

The data to study and identify the regions where the degradation and where development “growth” of the corals occurred, will be updated every 26 days after new analysis.

2.5.3 Requirements Analysis accomplishment

During the requirements analysis application, all the stakeholder requirements has been analyzed considering the research, definition and scope, further subdivided into four different scenarios: Plan of Verification and Tests, Thermal Test, Transport and Sensing. Each one of them are part of one type of scenario (development/product) as follow. The first one cited “Plan of Verification and Tests” is part of the organization during development scenario; “Thermal Test” is part of the product in a non-operational scenario; “Transport” represents Satellite transport to the launch pad being part of the organization in a non-development scenario; and “Sensing” is part ofthe product in an operational scenario.

As part of the requirements control, all the main objectives were listed for TBD verification, containing the following options: P - performance, F - functional, C - capacity and R - restriction, analyzing compliance, concerns, constraint and verification (procedure and type of test or simulation).

From the stakeholder requirements, the systems concurrent engineering allows to define its acceptance criteria and qualification strategy. Subsequently, the system requirements analysis was performed from the stakeholder requirements point of view for the product in the operation scenario, for product in the nonoperation scenario, for organization in the development scenario and for organization outside the development scenario.

3 | CORALSAT

The need of who are involved in mission development is to check the aforementioned coral bleaching, so that, based on whitish coastal areas (coral death behavior), they will be able to take swift action prior to solve the problem. At beginning of the project, the idea given was the creation of a satellites constellation for reach the purpose. These satellites would be responsible for collecting the images of the area composed of corals and these images would be transmitted to INPE from where they would be made available to the Navy, IBAMA and other environmental agencies as well as made available to the public when required.

After that, when Navy receives the image data, they will be able to redesign their routes in order to protect the vessels that would navigate through the affected area, and IBAMA would take actions related to the corals protection and conservation. Although the primary concept presented would fully address stakeholder needs, the same cannot be said of the budget required to design such a constellation; for this reason another idea was proposed: the use of only one satellite to carry out the task. The new proposal fits both the needs of all stakeholders and their financial constraints. Figure 1 shows how performance model was approached.

Developed to operate during five years, CoralSat is able to monitor a coastal strip of 8,500 kilometers and collect the data within the 26 day period with 0.5m of precision. Thus, with the information collected, it is possible to detect not only the corals whitening, but also the speed of their degradation and their growth. Therefore, the satellite is able to accomplish its purpose within the expected and following the requirements and acceptance criteria.

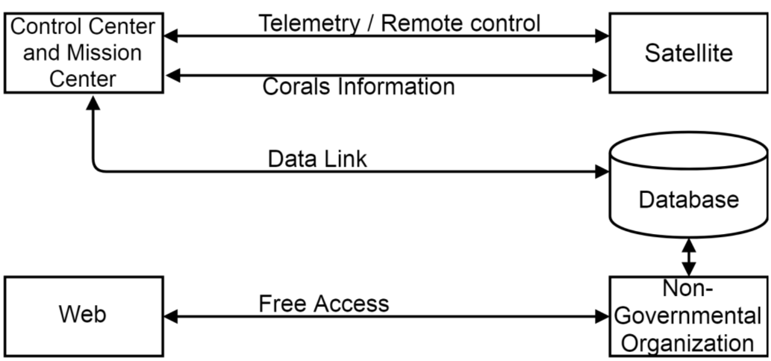

Figure 1. CoralSat performance model.

The application of systems engineering for the development of this mission (CoralSat) took about three months to be completed. The project was divided into several parts, so that each part of the strand could be applied separately and finally, each part of this mission received the proper decomposition of its purpose. One presentation was arranged with every part of the product, since its conception to the development phase. This presentation make it clear that the product perform as a whole more than its parts alone: this proved the value of the application of Systems Engineering in achieving the excellence of the product.

4 I APPLICATION OF SYSTEMS ENGINEERING

This chapter presents the approach used to apply systems engineering in the CoralSat project, with objective to demonstrate how this technique involves all areas and professionals since of the design of the project, all elements of the life cycle, the conception, until disposal of the product INCOSE (2015). From this assumption we emphasize here the stakeholder analysis, requirements analysis, functional analysis, architecture and detailed design. In order to exemplify the systems engineering processes, this article demonstrates an example of operational scenario (Sensing) and an organizational scenario (test plan and verification).

During the development, all analyses and methods applied for the CoralSat mission are implemented trought of Concurrent Engineering of systems, in other words, each analyze of the life cycle scenarios includes product and organization at the same time.

4.1 Stakeholders Analysis

The Stakeholders analysis of the CoralSat mission was made based in the choice of four scenarios of the life cycle processes of the mission, to be broken down. These four distinct scenarios are: test plan and verification, thermal testing, transport and Sensing. The sensing operation scenario, the test plan and verification of organization development scenario, the thermal testing are non-operational scenarios, while the transport of the satellite to the launch base is the organizational scenario of not-development.

To decompose the scenarios was used the analysis technique MoEs to analyse the measures of effectiveness, or the metrics which will be measured the satisfaction of a stakeholder with the products produced by the technical effort, IEEE (2005).

The purpose of using MoEs was to estimate the stakeholder satisfaction throughout the product life cycle. For this we applied the MoEs, approaching the following characteristics: if they are related to the performance; if they are simple to declare; if they are testable; if they are complete; if they are quantitatively measured and if they are easy to measure, AirForce (2013).

As an example of the use of MoEs for measures of effectiveness, the Figure 2 shows the product in the operating scenario: Sensing. The measurement is performed upon calibration of the satellite sensor.

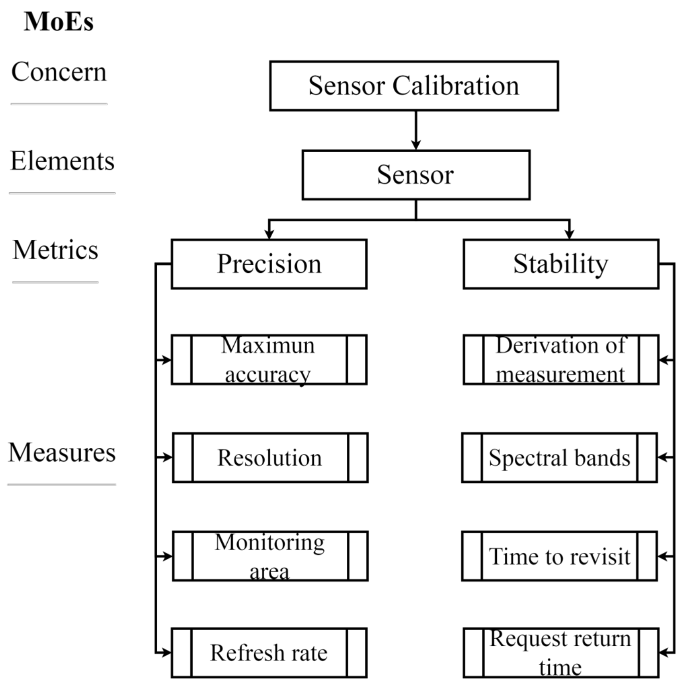

Figure 2. MoEs of the product in operation scenario: Sensing..

The purpose of apply of the MoEs technique to the sensor was to analyze its performance, effectiveness and measure the ability of it to meet their operational usages laid down over your life cycle.

4.2 Requirements Analysis

Requirement can be defined as: a required atribute in a system; a statement that notes a resource; characteristic or quality factor of a system to make it useful, has value to a client or user, Young (2004). The requirements analysis consists in activities concerning with research, definition and the scope of a need of the concerned persons.

From the conceptual definitions of requirements analysis, within each scenario were defined the stakeholders requirements and these were decomposed into organization requirements, as an example, we have in the scenario Test Plan and Verification like a development scenario for the organization and like stakeholder the testing team, who shall follow the standards and procedures set out in the CoralSat “quality assurance document”, which has been decomposed into requirements such as:

- The organization shall configure the quality assurance documents for the CoralSat project;

- The organization shall configure the standards required by the quality assurance of the CoralSat project;

- The organization shall create a list of the activities of the test and verification plan, where each document contains what is necessary for the accomplishment and validation.

4.3 Functional analysis

Functional analysis results in a description of the structure and the required functional behavior, in other words, what the system shall be do, where the structure shows a static view of the system functions and the behavior defines how the when and while functions shall be executed, which are described by modes and state transitions, states and state conditions INCOSE (2015). The Figure 3 shows the functional mode transition diagram for the product in operating scenario: Sensing, and Table 1 the projection of the modes in each circumstance.

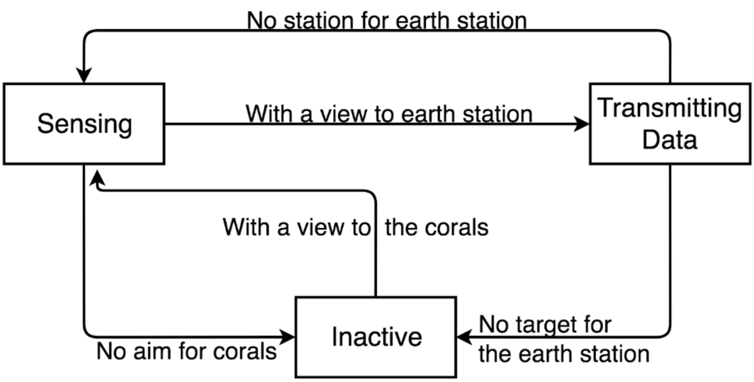

Figure 3. Functional transition diagram of modes.

For the functional analysis of the CoralSat, after decomposing the life cycle for each of the scenarios chosen, a functional context diagram was created, which represents the ows exchanged between the elements of the system environment. Besides the functional context diagrams, an architecture context diagram was made for each scenario, which in turn represents the means by which the exchanges are made between the system and the environment around it. Figure 4 shows the functional context for the product in the operating scenario: Sensing.

MODO	CIRCUMSTANCES	
	Aimed at the corals	Aimed at earth station
Sensing	Yes	Yes
Transmitting	Yes	Yes
Inactive	—	—

Table 1. Analysis of circumstance and modes.

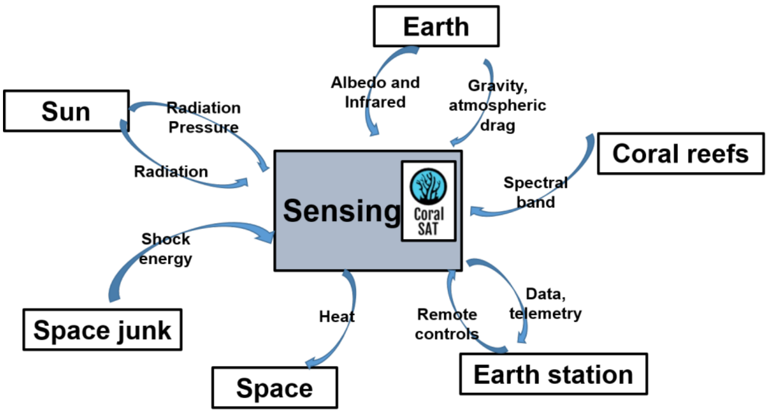

Figure 4. Context analysis for the product in the operating scenario: Sensing.

With the elaboration of these diagrams it was possible to observe which elements in the system environment exchange energy, material and information with the CoralSat system. With the identification of their ows, it was possible to define the logical external interfaces between the system and its environment. The Figure 5 represents the architecture context diagram for the product in the operating scenario: sensing.

During the context analysis, a list of elements which interacting with the system was created for each relevant scenario. For each chosen scenario, its analysis was aimmed to identifying elements in the system environment and if is required an additional analysis to the scenario.

For each stream and each element in the system environment, a data dictionary with more detailed specifications was made, which was related to the external functional interfaces of the CoralSat system.

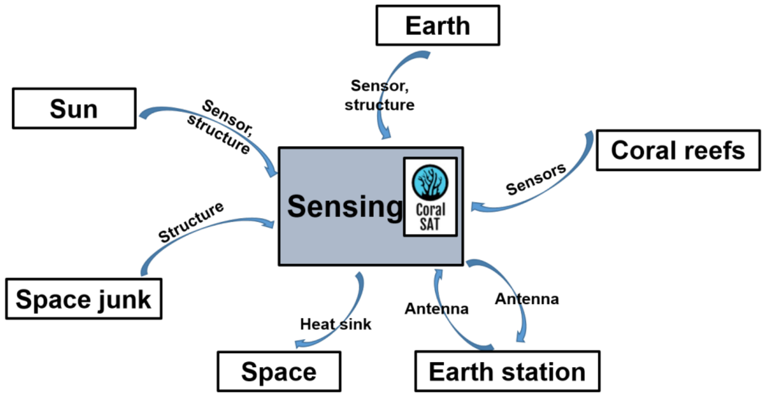

Figure 5. Product in Operation Scenario: Sensing.

Subsequently, the circumstance analysis was started, where the circumstances are the combinations of possible attributes values of elements in the environment and the ows in the system context. This analysis was performed for the four scenarios and had aimed to identify each element in the environment and/or each ow in the context diagram the most relevant attributes and describing them, INCOSE (2015). The circumstance analysis served as the basis for carrying out the Risk Analysis by Circumstances and Flows for the four analyzed scenarios. To the analysis of danger by non-function, they were defined some points to be observed like the system failure, cause, probability of occurrence, impact, detection and risk.

4.4 Architecture

Based on the decomposition of the four chosed scenarios from the mission life cycle processes, the architecture of the CoralSat project was defined and the first step was to create a generic physical architecture of product and the generic physical architecture of organization, as shown in the figure 6 and 7 and later, we were attributed their functions.

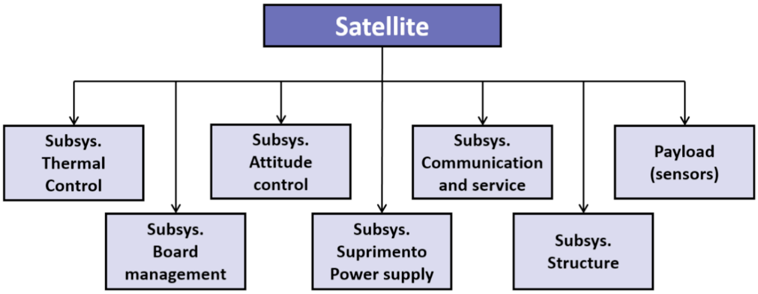

Figure 6. Generic physical product architecture.

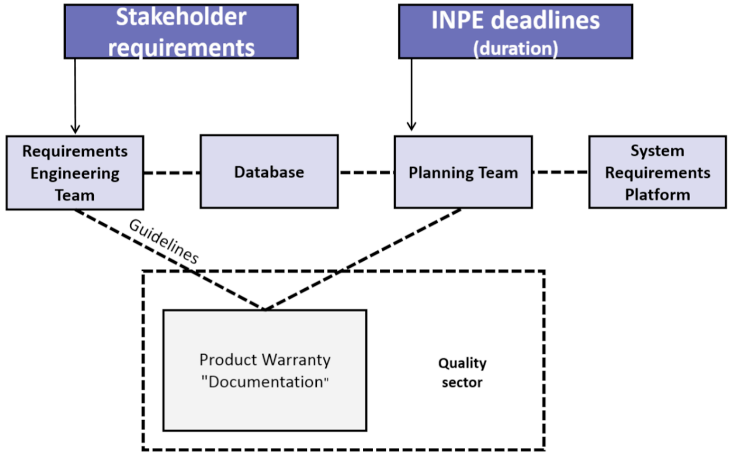

Figure 7. Generic physical organization architecture.

The physical architecture functions reect requirement characteristics of the physical component of the CoralSat mission.

4.5 Detail design

The detailed design was created from the generic Physical Product Architecture, presented in figure 5, the instantiated physical architecture of the product in operation is to specify how the systems components will be acquired Larson (2009).

The Figure 8 consists in an architecture block diagram of the CoralSat system, based on the physical architecture described in the architecture ow diagram and architecture interconnection diagram, which shows the types of components that the Coral-Sat system can have, these components must be specified during the detailed design.

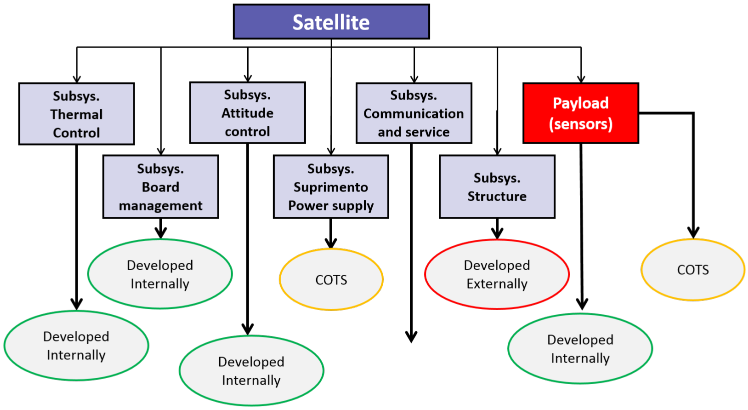

Figure 8. Instantiated physical architecture of the product in operation.

To exemplify, a model of component specification was written for one of the components from the architecture block diagram. This model consisted of a list of documents containing information like: applicable documents, referenced documents, acronyms abbreviations, definitions, acronyms, requirements (and targets), identification of external interfaces among others, the document was called “Index of the Specification of the Payload”.

The CoralSat detailed design was the basis to specify the kind of development (internal, external, COTS or reuse).

It was defined, for CoralSat project, to be use 100% of the PMM would be used and at least 70% of the payload equipment used, should be provided or developed by INPE. In addition, to use remaining EEE parts from other projects.

As a result of the detailed design activity of project, we get the low-level requirements of the specified system.

5 | DISCUSSIONS

One of the main results of the systems concurrent engineering application in the development of the work was the concatenation of its different scenarios and, how these ended up arranged in the final presentation. During the work diagram development part of each scenario, it was possible to identify how the establishment of these took shape: instead of considering the scenarios as topics of each of the six mentioned divisions, it was de_ned that the opposite would be more viable in terms of visualization and understanding.

In this way, the final presentation consists of the general considerations about the system and, in addition, the four scenarios, each containing their respective parts. This decision made the way the work presented clearer, and facilitates the recognition of the topics covered in presentation mode.

Concerning the de_nition of functions, the presentation contained only DFD and STD. The PAT was not presented because of how each part of the scenarios would be seen in the presentation and its tabulated form with a vast amount of information to be allocated would harm your viewing and would not convey your content intuitively. In the final presentation, the structured view of DFD and STD proved more understandable resulting in a better and faster assimilation of their purposes. As shown in Figures 9 and 10 with DFD and STD diagrams for “Plan of Verification and Tests”.

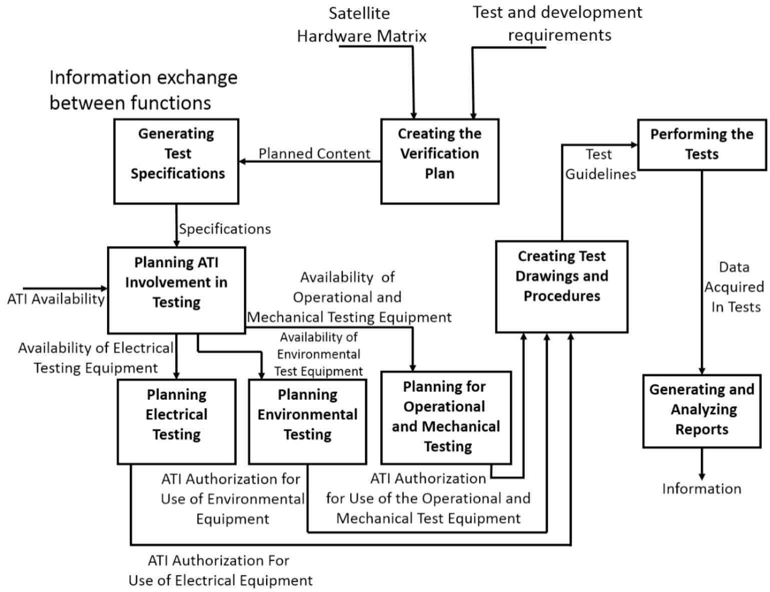

Figure 9. DFD - for Test Plan and Verification.

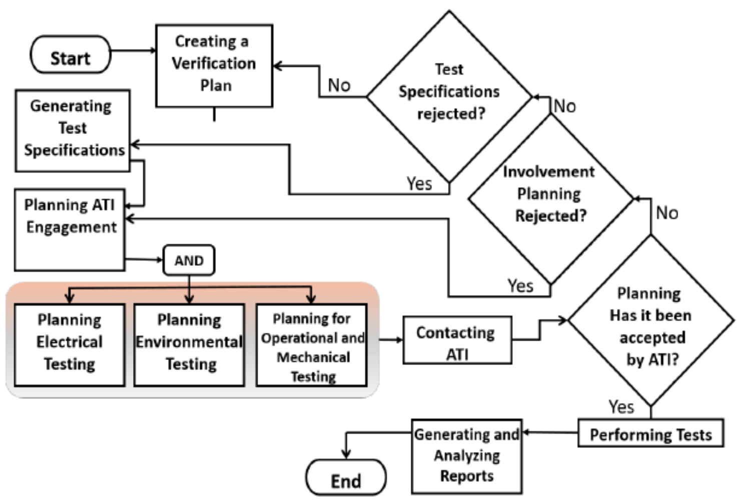

Figure 10. STD - for Test and Verification Plan.

Finally, in its entirety, it was possible to apply all the systems engineering tools proposed by Loureiro (1999), in the project, this facilitated the work unfolding. The final presentation of the project had succeeded on converting the idea of the method as well as all points discussed in this article.

6 | CONCLUSIONS

The application of the systems engineering approach has proven to be very effective in the development of complex systems; its application in the Coral-Sat project lifecycle has allowed to glimpse problems that can be solved throughout the product or system development. Understanding the processes of systems engineering made possible the CoralSat system modeling, from its initial phase where it was implemented the product and organization mission analysis, to its completion when this system is ready for operation. With this approach aforementioned, it was possible to consider and analyze possible solutions to problems encountered during development through stakeholder analysis, requirement analysis, functional analysis, architecture and detailed design.

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