System Concurrent Engineering of a People Tracking Satellite, a Case Study

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Abstract

Developing satellite systems involves managing the challenges that come with the complexity of the technological aspects of these systems and their very dynamic manufacturing and business organization. In such a challenging environment, the success of this development is dependent on the capacity to shorten development cycle time, reduce cost, manage risks and, at the same time, define product and organization requirements and solution that satisfy the stakeholders' needs. Traditional development approaches provide only a partial identification and understanding of the elements of this environment and their interactions, therefore, to achieve a satisfactory result it is recommended to develop such complex systems using a combination of methods from different approaches. Loureiro [1] proposed a framework and method that extends the application of the System Engineering process to life cycle processes and their performing organizations and applies Concurrent Engineering at all levels of the hierarchical product breakdown structured in order to help on development of complex products. This paper presents the integrated System Engineering and Concurrent Engineering steps for the case study of a development of a People Tracking Satellite using Loureiro's approach. The feasibility of this methodology as well as its capacity to addresses the needs for a scope of a People Tracking Satellite development, for the integration of product, process and organization and for complexity management are demonstrated.
Keywords: Satellite, People Tracking, System Engineering

1. Introduction

Location based services (LBS) define the broad spectrum of technologies which can calculate the position of a receiver. There are many types of LBS which function at varying degrees of accuracy and scope. The most widely used LBS relays the location of mobile phone users through the global positioning system (GPS) to emergency units. This system relies on the individual's dependency on the phone. This is not too difficult in modern society as mobile phones have become so essential to our daily lives [2], on the other hand, exactly due to this dependency it is not possible to provide this kind of service in remote areas where mobile phone signals are not available. One way to solve this is to use a specific gadget that has the capability to be tracked directly by a satellite.

This paper has the intention to present a system concurrent engineering approach case study for the development of a People Tracking Satellite to provide an LBS not dependent on mobile phones.

This paper is organized as following: Section 2 summarizes the systems engineering, concurrent engineering and system concurrent engineering approaches. Section 3 presents the modelling of the proposed case study using the systems concurrent engineering approach, and finally Section 4 concludes this paper.

2. System Engineering, Concurrent Engineering and System Concurrent Engineering (Total View Framework)

Complex product manufacturing industry faces a very dynamic and highly competitive global marketplace. In such a dynamic environment, the ongoing success of a development organization is translated by its capacity to continuously shorten development cycle time, reduce cost, manage risks and, at the same time, improve product performance. Traditional development approaches provide only a partial picture of these elements and their interactions. In order to cope with product inherent complexity and with the complexity that may arise from changes, it is necessary to adopt an integrated development approach for complex product development [1].

The following subsections presents a brief description of System Engineering and Concurrent

Engineering approaches, followed by an overview of the Total View Framework approach proposed by Loureiro [1], which integrates System Engineering and Concurrent Engineering in a same framework and method, in response to the discussed needs for complex product development.

2.1 System Engineering

According to INCOSE [3], System Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem: operations, cost and schedule, performance, training and support, test, manufacturing, and disposal. System Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.

2.2 Concurrent Engineering

Concurrent Engineering is a systematic approach to the integrated, concurrent design of products and their related processes, including, manufacturing and support. This approach is intended to cause the developers from the very outset to consider all elements of the product life cycle, from conception to disposal, including quality, cost, schedule, and user requirements [4].

2.3 System Concurrent Engineering (Total View Framework)

The ‘total view framework’ was proposed by Loureiro [1] for the integrated development of complex products encompassing the System Engineering and the Concurrent Engineering. The 'total view framework' aims to identify the attributes of, not only the product but also its life cycle processes and their performing organizations and the relationships among those attributes at the integration dimension. The analysis dimension defines the different types of analysis that are undertaken to identify the requirements, functions and physical aspects of the product, process and organization elements of the system. The structure dimension defines how complex the system is to be structured, which means that the layers of the hierarchy correspond to the end product breakdown structure. Fig. 1 presents the scheme of the 'total view framework’ approach and fig. 2 and 3 detail the integration and structure dimensions respectively.

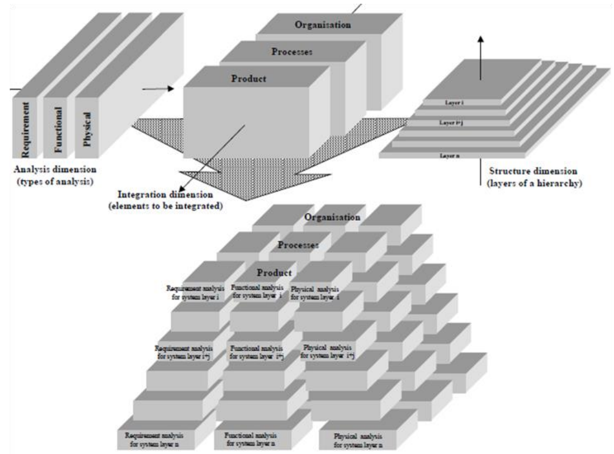


Fig. 1. Total View Framework

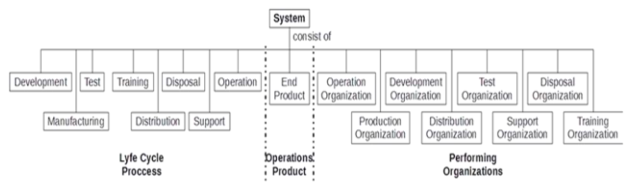


Fig. 2. Integration Dimension

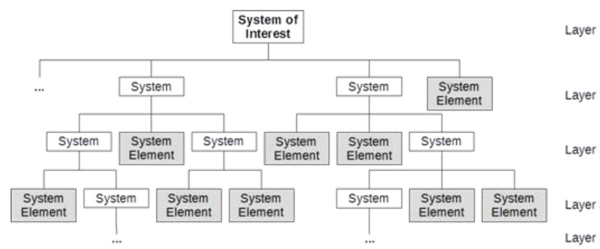


Fig. 3. Structure Dimension

2.4 Total View Framework method

The method proposed by Loureiro [1] is summarized on the following paragraphs.

Requirements analysis is triggered by the identification of some initial and obvious stakeholders and their needs. The requirements analysis process then identifies other stakeholders, their concerns and their requirements. As part of the analysis process, in the stakeholder requirements set, functions, performance, conditions, constraints, assumptions and goals are identified.

Functional analysis translates the technical requirements into a functional architecture, from which functional attributes are derived. Functional attributes describe each element in the functional architecture. The functional architecture describes the functional arrangements and sequencing of sub-functions resulting from decomposing the set of system functions to their sub-functions. Functional analysis is performed without consideration of a design solution.

Physical analysis translates the functional architecture into a physical architecture from which physical attributes are derived. Physical attributes describe each element on the physical architecture. The physical architecture provides an arrangement of elements, their decomposition, interfaces (internal and external), physical constraints, and designs.

The analysis process intends to provide a structured and iterative definition of the problem and development of the solution. The iterative nature of the analysis process is characterized by the requirements, design and verification feedback loops.

Requirements, functional and physical analysis processes are carried out through the simultaneous modelling of product, process and organization for each layer of the hierarchy.

The following section presents a case study to demonstrate the feasibility of the approach summarized above as well as its capacity to address the needs for a scope of a People Tracking Satellite system development.

3. Case Study

The space product chosen for the case study is the “People Tracking Satellite” (PTS). Such satellite system is part of a global LBS system that will allow users to be located and send security messages from anywhere in the Brazilian territory to their pre-defined contacts. The case study is structured in five steps: mission definition, life cycle processes and stakeholder analysis, functional analysis, architecture design process and detailed design.

3.1 Mission Definition

The mission definition consists of six activities: write down the statement of the need; identify initial stakeholders; derive goals, objectives, measures of effectiveness (MoEs) and qualification strategy; depict the “as-is” operational scenarios and “to-be” operational scenarios; list capabilities and constraints, and derive the concept of operations and the system operational architecture.

The need statement for the system was defined, as “the user must be able to be located and send a security message in an emergency situation throughout the Brazilian territory”. Starting from the defined need statement and using the IDEF0 (“Icam DEFinition for Function Modeling", where ICAM is an acronym for "Integrated Computer Aided Manufacturing") methodology it is possible to identify the system´s initial stakeholders considering output, input, control and mechanisms dimensions. The IDEF0 diagram is shown in Fig. 4.

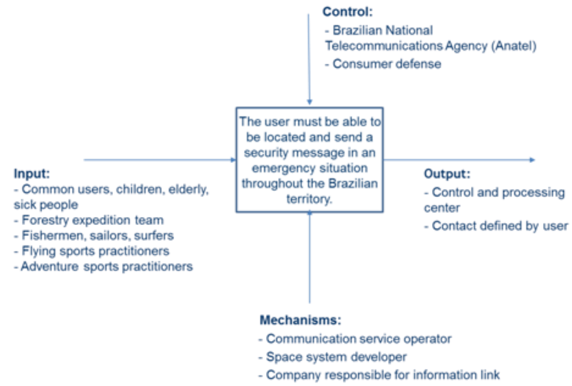


Fig. 4. IDEF0 diagram

For Larson [5], the main purpose of mission analysis is to quantify the performance of the system and its capacity to accomplish the mission objectives. To achieve such purpose it is necessary to determine how well the systems work and how well the system meets the mission objectives. How well the systems work is defined by its goals and objectives, in turn, how well the system meets the mission objectives is defined by MoEs and qualification strategy. The mission analysis was conducted by translating the key stakeholder’s expectations into goals and its related objectives, and then by defining the MoEs and qualification strategies from such goals and objectives. Fig. 5 and 6 present such parameters.

Goals	Objectives
Provide user's location and message.	Provide latitude and longitude location data with 1 km precision and text message with 10 characters.
Provide periodic location tracking and message delivery.	Information (location / message) made available periodically in an interval of 100 minutes.
Assist rescue teams.	Reduce rescue time by 40%.

Fig. 5. Goals and objectives

Nº	MoE	Description	Qualification strategy
1	*Detection*	The system must be able to receive signals in the UHF frequency range with low power levels.	Test procedure for receiving data during operation. (Documentation review).
2	*Coverage*	The system must cover all Brazilian territory.	Receive data from the user's device in the national territory. (Test)
3	*Persistence*	The system must monitor the coverage area at least once within two hours period.	Receive data from the user's device in the coverage area at least once every two hours. (Test)
4	*Timeliness*	The system must send notifications to the control and processing center within 5 minutes (target), with 1 minute tolerance (limit).	Control and processing center must receive system notification within 5 minutes after system has received signal from user's device. (Test)
5	*Geolocation accuracy*	The system must locate the user with accuracy of 1 km (target), with 200 m tolerance (limit).	Verification through the GPS technical specification. (Documentation review)

Fig. 6. MoEs and qualification strategy

After goals, objectives, MoEs and qualification strategies were defined, it was possible to develop the “As is” and “To be” operational environment and scenario. The “As is” operational environment and scenario represents how the problem is currently undertake without the proposed solution. According to Larson [6], the "To be" environment describes what operators and users need and how the system in development and its associated elements will meet their requests. These operational environments and scenarios are presented in fig. 7 and 8.

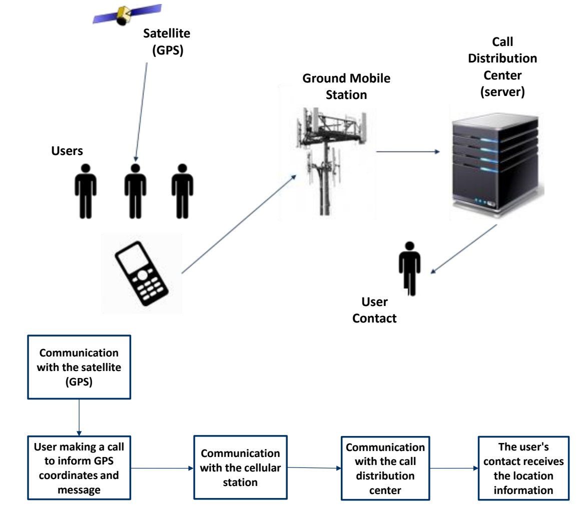


Fig. 7. "As is" operational environment and scenario

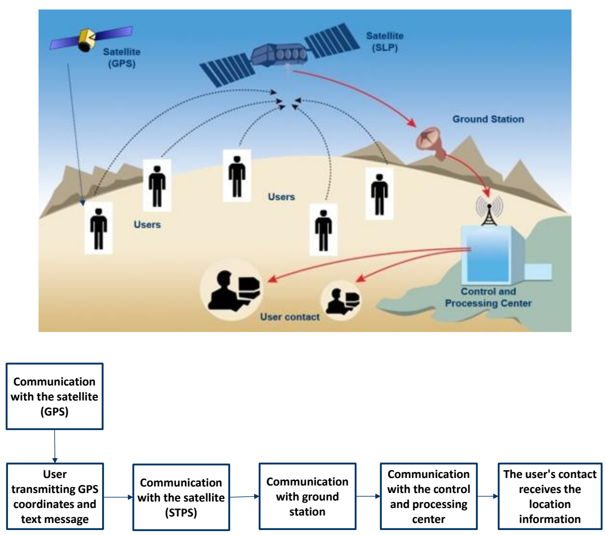
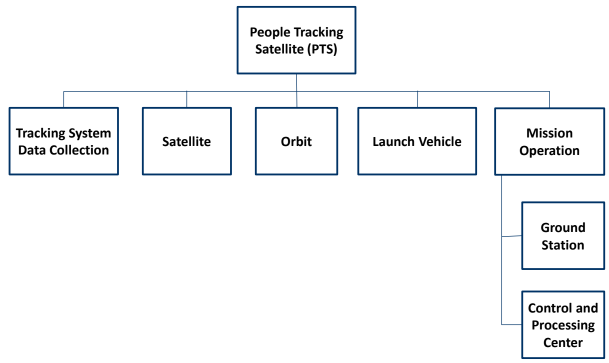


Fig. 8. "To be" operational environment and scenario

Another important step in mission definition is to list the system's capabilities and constraints. The main capabilities identified for the system were: user to be capable of being located, user to be capable of sending signal and text message and user to be capable of receiving and sending GPS coordinates. In turn, several constraints were identified such as: absence of GPS signal constraints, geographic constraints (restricted to the national territory), time constraint, and cost constraint.

According to INCOSE [3], the Concept of Operations describes the way the system works considering the operator's perspective. For Larson et al. [6], a good Concept of Operations reflects stakeholders' expectations in verbal and graphic perspectives, becoming a platform for supporting the validation of system's architecture and technical requirements. Following Larson's recommendations, the Concept of Operations (ConOps) and the System's Operational Architecture of the "People Tracking Satellite" were developed as shown in fig. 9.



Users	Positioning and message data				
	Satellite - PTS		Telemetry data / positioning and message data		
Positioning		Satellite - GPS			
	Telecomand		Ground Station	Telemetry data / positioning and message data	
			Data request	Control and Processing Center	Positioning and message data
				Data request	User's Contact

Fig. 9. Concept of Operations and System Operational Architecture

The mission analysis is concluded when the Concept of Operation and System's Operational Architecture are defined. Therefore, it is possible to start the Life Cycle Processes and Stakeholder Analysis.

3.2 Life Cycle Processes and Stakeholder Analysis

According to ISO IEC 15288 [7], every system has a life cycle that can be described using an abstract functional model that represents the conceptualization of a need for the system, its realization, utilization, evolution and disposal. A system progresses through its life cycle as the result of actions, performed and managed by people in organizations, using processes for execution of these actions.

The System Engineering standards expand the scope of a system, including the end-product element and also its life cycle process elements. The requirements are set for the entire life cycle and its processes.

It is a key part of Systems Engineering process to anticipate needs from the whole life cycle and perform the integration of stakeholder requirements from product and organization perspectives.

For the purpose of this case study, the PTS was chosen as the system of interest inside the global LBS system; therefore, all analyses from now on will be performed for this system only. Additionally, since the complete analysis grows exponentially according to its progress, for simplification purpose, only few examples of each step will be included in this paper.

3.2.1 Life Cycle Processes

The life cycle for space systems of the ECCS-M-ST-10C [8] was adopted for the System-of-Interest (fig. 10), and the life cycle processes are represented in the fig. 11.

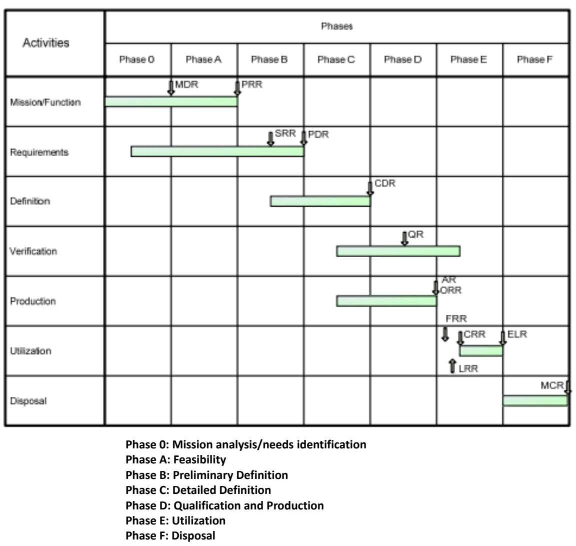


Fig. 10. Space Systems Life Cycle

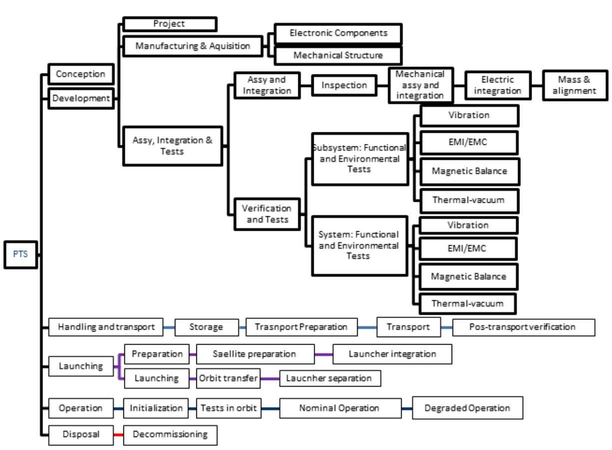


Fig. 11. PTS Life Cycle Processes

3.2.2 Life Cycle Processes Scenarios

Part of the requirements analysis process is the identification and definition of a set of scenarios that define the range of anticipated uses of the product when in operation and when in non-operation as well as the scenarios of development organization and other organization in order to cover the development of product, processes and organizations in a simultaneous and integrated way.

For the purpose of this paper, two scenarios only were selected to perform the remaining analysis: Satellite in Orbit Correction (product when in operation) and Assembly, Integration and Test - AIT (development organization).

3.2.3 Stakeholder Analysis

The objective is to identify additional stakeholder requirements, by identifying additional stakeholders (fig. 12), their concerns (fig. 13) and MoE (fig. 14) in the selected scenarios.

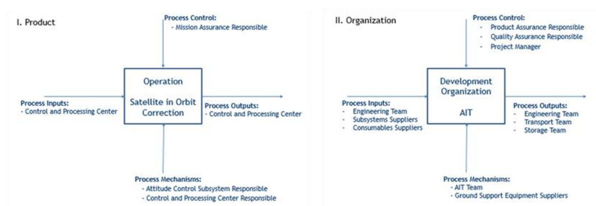


Fig. 12. Stakeholders identification for each scenario using IDEF0 analysis

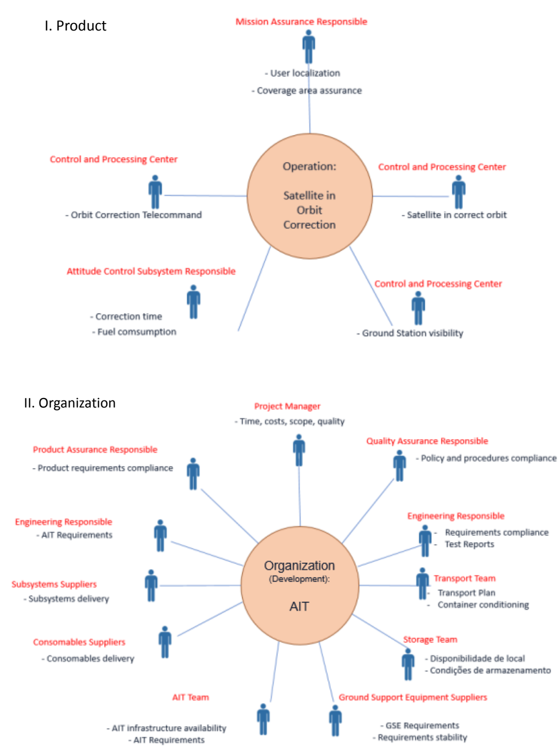


Fig. 13. Stakeholders concerns

Scenario	Stakeholder	Goal	Question	Metric	Measures
Product: Satellite in Orbit Correction	Control and Processing Center	To correct the orbit	The orbit had been corrected?	Positioning measures	Distance and seed
Organization: AIT	AIT Team	To get the necessary infrastructure to AIT activities	The available infrastructure had been suficiente to perform all the AIT activities?	Compliance with AIT procedures	AIT necessary infrastructure check list

Fig. 14. Scenarios Stakeholders MoE

3.2.4 Stakeholders Needs and Requirements

For each scenario and each stakeholder, the needs were identified (fig. 15) and requirements defined (fig. 16). Therefore the first version of the Stakeholder Requirements Document is able to be written as well as after further analysis, a System Requirements Document can also be written.

P/O	Scenario	Stakeholder	Needs
Product	Satellite in Orbit Correction	Control and Processing Cener	To obtain the orbit information
		Attitude Control Subsystem Responsible	To get the correction manouver data
		Mission Assurance Responsible	To get the satellite in the correct orbit
Organization	AIT	Engineering and Product Assurance Responsibles	To get the test reports
		Subsystems Suppliers	To get the subsystems requirements
		Consumable Suppliers	To get the material description, quantity and delivery date
		AIT Team	To have available the AIT infrastructure
		Ground Support Equipment Suppliers	To get the ground support equipment technical specification
		Storage Team	To have an available and approppriate storage area
		Transport Team	To get the transport plan
		Quality Assurance Responsible	To get the quality assurance system implemented
		Project Manager	To accomplish the development plan (cost, delay, scope and quality)

Fig. 15. Stakeholders needs

P/O	Scenario	Stakeholder	Concern	Nr	Requirement	Need Level (1)	Constraint (2)	Verification (3)
Product	Satellite in Orbit Correction	Control and Processing Center	Orbit Control	Req 01	The Control and Processing Center shall obtain the orbit information	M	N	T
Organization	AIT	AIT Team	Infrastructure Availability	Req 02	The AIT Team shall have available the AIT infrastructure	M	Y	D

Legend: Must (M), Should (S), Could (C), Wish (W) (2) Constraint: Yes (Y), No (N) (3) Test (T), Inspection (I), Demonstration (D), Analysis (A)

Fig. 16. Stakeholders requirements

3.3 Functional Analysis

Up to this point the requirements of the system have been defined according to the interests and concerns of the stakeholders. Now the system will be analyzed according to its functions and the interactions of these functions with the other interfaces and its environment.

3.3.1 Product and Organization Functional Contexts

After identifying the scenarios of the lifecycle process, it is necessary to create a context where the product and the organization exchange material, energy and information with its environment. The fig. 17 shows the functional context of the satellite during a typical operational scenario and the organization during a development scenario.

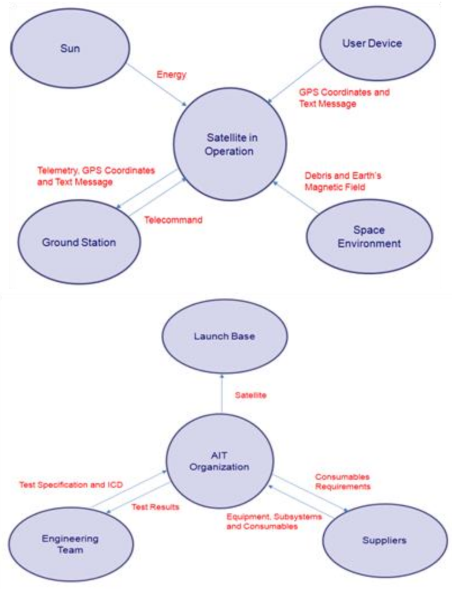


Fig. 17. Functional context of the product during operation scenario and organization performing the development scenario

3.3.2 Circumstances and Modes in Contexts

The circumstances are the conditions that each scenario of the lifecycle process may be subject for each state of its elements. For each circumstances identified it is important to analyze the different modes of operation that the product and the organization will assume under each circumstance. The fig. 18 and 19 present an example of the circumstance of the functional contexts of the product and the organization.

Element	State of the Element	Circumstance	Mode
Ground Station	Telecommand Transmitting	Free Line-of-sight	Transmitting
		Partial Line-of-sight	Wait
	Telemetry Receiving	Free Line-of-sight	Receiving
		Partial Line-of-sight	Wait

Fig. 18. Circumstances in functional context of the product during the operation scenario

Element	State of the Element	Circumstance	Mode
Engineering Team	Defining Test Specification	Full Team Available	Regular
		Partial Team Available	Delayed
	Writing ICD	Full Team Available	Regular
		Partial Team Available	Delayed

Fig. 19. Circumstances in functional context of the organization performing the development scenario

3.3.3 Mode Analysis

The mode analysis consists of determining the transition between the different modes identified for each element within the functional context of the product and the organization. fig. 20 shows the mode transition diagram for the functional context of the satellite during a typical operational scenario and for the organization during a development scenario.

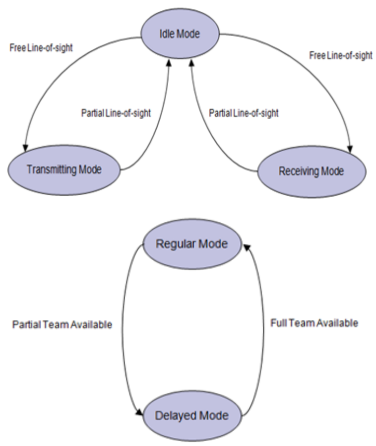


Fig. 20. Mode Transition Diagram of the product during the operation scenario and the organization performing the development scenario

3.3.4 Essential Functional Architecture

The essential functions are the generic functions that are not related to any specific technology. These essential functions and its functional interfaces make up the functional architecture. The fig. 21 and 22 illustrate the functional architecture of the satellite during a typical operational scenario and for the organization during a development scenario.

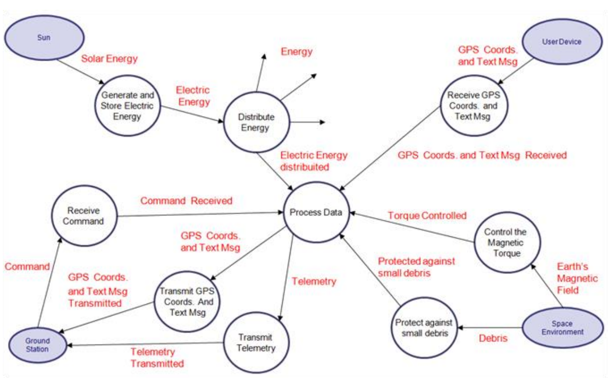


Fig. 21. Essential functions of the product during the operation scenario

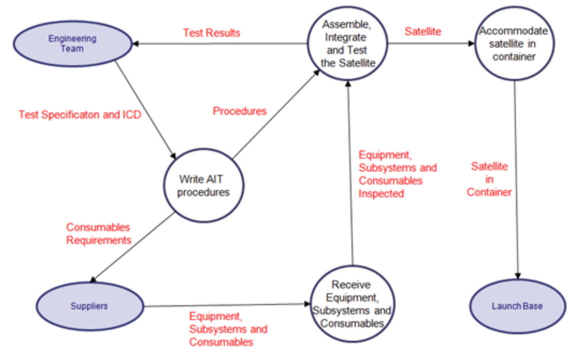


Fig. 22. Essential functions of the organization performing the development scenario

3.3.5 Physical Context

The physical context presents the physical interfaces that are used by the flows to exchange material, energy and information between the elements already identified from the functional context. The fig. 23 presents the physical context of the satellite during a typical operational scenario and for the organization during a development scenario.

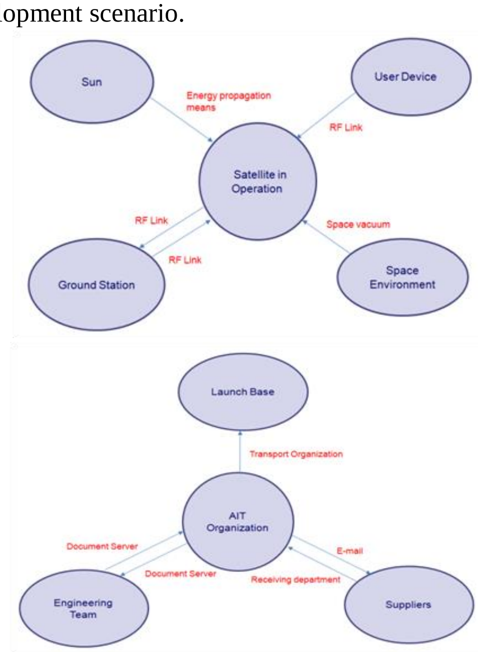


Fig. 23. Physical context of the product during the operation scenario and the organization performing the development scenario

3.3.6 Hazard Identification and Risk Analysis

Hazard identification is the process of identifying the main hazards to the system during its lifecycle. The risk analysis is the process of assessing the risk associated with each hazard identified for each circumstance of the scenario. The fig. 24 presents an example of the hazard identification and risk analysis of the satellite during a typical operational scenario and for the organization during a development scenario.

	Product	Organization
Circumstance	RF link with partial line of sight	Waiting for imported electronic componente
Hazard	Satellite not receiving telecommands or sending telemetries	Delayed delivery
Consequence	Impossibility of maneuvers for orbit corrections	Delay of the satellite AIT
Gravity	4	4
Cause	Failure of ground station antenna	Component failure during production
Probability	1	3
Difficulty of Detection	1	3
Risk (Gravity x Probability x Dificulty of Detection)	4	36
Mitigation Function	Prevention	Prevention, Correction
Verification	Test	Revision

Fig. 24. Hazard Identification and Risk Analysis of the product during the operation scenario and the organization performing the development scenario

3.3.7 Behavioural Analysis

The behavioural analysis of the system consists of identifying the conditions and the respective actions of the element to change from one state to another state. The fig. 25 illustrates the behaviour diagrams of the satellite during a typical operational scenario and for the organization during a development scenario.

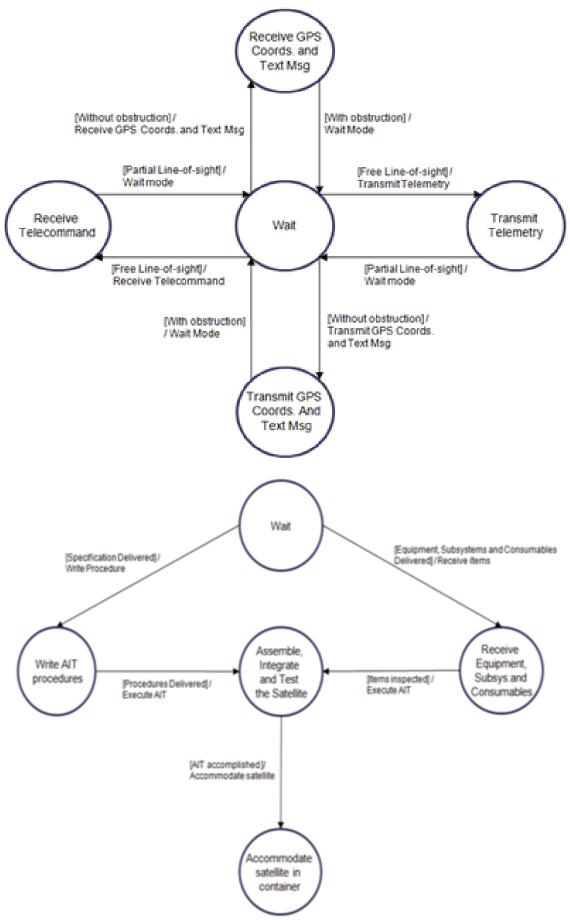


Fig. 25. Behaviour Diagram of the product during the operation scenario and the organization performing the development scenario

3.4 Architecture Design Process

At the architecture design process, the physical elements of the system are defined, where its components are linked to the functions already defined. In addition, for this work, the analysis process proposed in Loureiro [1] is applied, where the organization analysis is done, in order to configure the whole system.

3.4.1 Generic Physical Architecture

For the generic physical architecture the physical elements that compose the system are identified. Those elements are generics and, at this time, there is no performance specifications about them. Fig. 26 shows the generic product architecture and fig. 27 shows the generic organization architecture, both for the initially chosen scenarios.

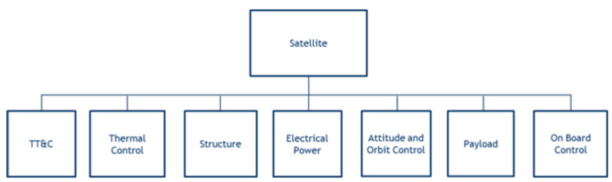


Fig. 26. Generic Product Architecture

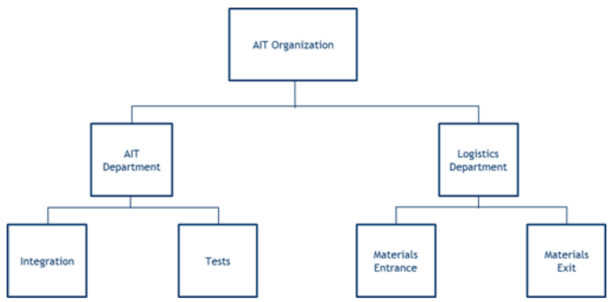


Fig. 27. Generic Organization Architecture

3.4.2 Requirements and Functional Allocation

Based on the functional analysis, the generic architectures were proposed and, at this point, each function in the functional architecture must be allocated to the components in the physical architecture. Each function identified must be allocated and performed by only one component or element. Fig. 28 and 29 show the allocation matrix for product and for organization, respectively.

	TT&C	Thermal Control	Structure	Electrical Power	Attitute and Orbit Control	Payload	On Board Control
Receives and stores solar energy		X		X			
Distributes energy				X			
Receives telecommand	X						
Data processing							X
Sends location info and messages						X	
Send telemetry	X						
Receives location info and messages						X	
Receives influence of the magnetic field			X		X		
Receives influence of debris	X		X				

Fig. 28. Allocation matrix for product

	AIT Department	Logistic Department
Receives the documentation, prepares the ait procedure and perform assembly, integration and testing	X	
Sends the test results	X	
Sends consumption material requirements	X	
Receives subsystems, componentes and material requirements		X
Sends the satellite		X

Fig. 29. Allocation matrix for organization

3.4.3 Solutions Identification: Morphological Chart and Decision Analysis

Considering the generic physical architecture, some generic elements were identified, and, from this analysis, alternatives shall be listed in a morphological chart. Fig. 30 shows the derived product morphological chart for the system of interest.

TT&C		Electrical Power		Attitude and Orbit Control			Thermal Control	Payload		Structure	On Board Control
Telecommand reception	Telemetry transmission	Generation	Battery	Sensors	Actuators	Propulsion		TX and RX			
UHF	UHF	Integrated solar panel in the structure	Ni-H	Solar sensor	Reaction wheel	Cold Gas	Heat pipes	UHF	UHF	Box + Ring	CAN bus
S-Band	S-Band	Single wing solar panel	NICAD	Star sensor	Torque coil	Mono propellant	Skin heater	S-Band	S-Band	Ring + Deck	MIL-STD-1553 bus
C-Band	C-Band	Double wing solar panel	Li-Ion	Magnometer	Double rotation	Bi Propellant	Radiators	C-Band	C-Band	Cylinder + Deck	SpaceWire
				Gyroscope	Rotation	Ion				Cylinder + Box	
					Gravity gradient	Electric					

Fig. 30. Morphological Chart

Based on the morphological chart, the next step is to select a method to evaluate the alternatives listed, and, an analytical tool can be used to perform decisions. These decisions are based on the MoEs previously defined, and, according Larson et al. [6], the design goals translate the development organization's policies that drive the design. A decision analysis matrix was chosen and performed in order to evaluate alternatives. In this work, an example for the propulsion subsystem is shown, where grades were given to specific thrust, safety and technological domain parameters. Fig. 31 shows the decision analysis matrix and the solution chosen (Mono propellant).

Criteria	Criteria weight	Cold gas	Mono propellant	Bi propellant	Ion	Electric
Specific thrust	40%	1	2	3	4	5
Safety	30%	4	3	3	3	2
Technological domain	30%	4	5	3	1	1
Total	100%	2,8	3,2	3,0	2,8	2,9

Fig. 31. Decision Analysis Matrix

3.4.4 Specific physical architecture

In order to represent the system architecture, an architecture flow diagram, an architecture interconnect diagram and an N2 chart were developed, both for product and for organization. Based on these diagrams and chart, the interfaces can be specified in an interface control document (ICD). Interfaces must be correctly specified due to the fact they are very important in a system development, and, for that, each interconnection identified must have its requirements or functions listed. Fig. 32 and 33 show the architecture interconnect diagrams for product and organization, respectively.

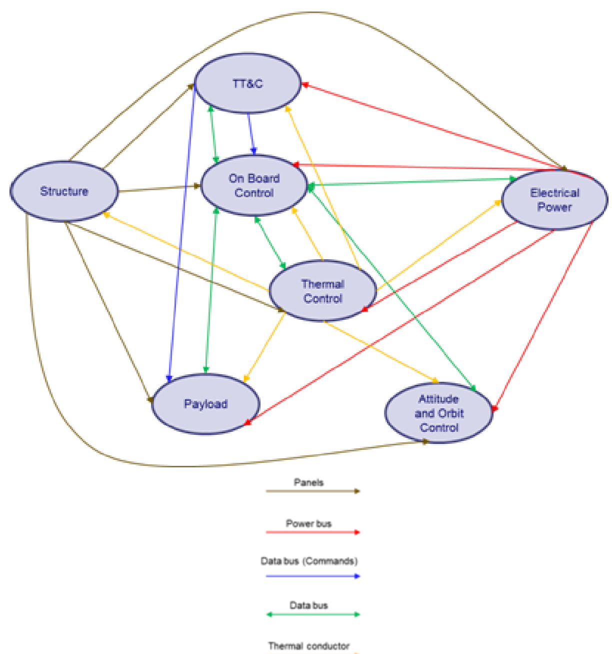


Fig. 32. Architecture interconnect diagram for product

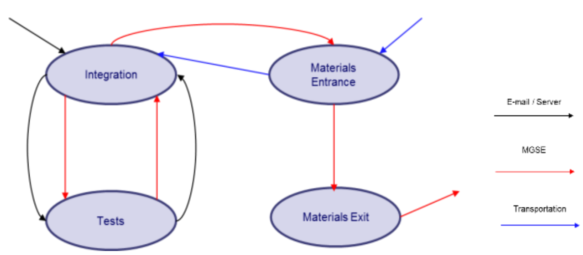


Fig. 33. Architecture interconnect diagram for organization

3.5 Detailed Design

At this point, the Product Breakdown Structure (PBS) were used in order to represent the system. Using the PBS, the decision about to buy or develop each system physical element must be done. Options can be internal development, external development, reuse or commercial off the shelf (COTS) acquisition. In addition, a specification for each element can be done in order to register the necessary information about the components. Fig. 34 shows the PBS and the indication about the options made for product. Fig. 35 shows the architecture block diagram for organization.

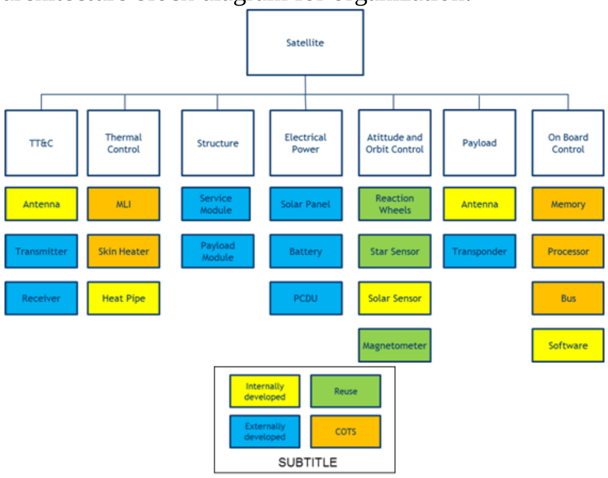


Fig. 34. Product Breakdown Structure (PBS)

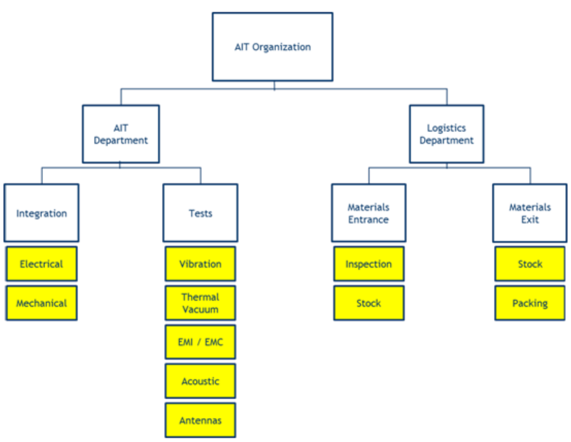


Fig. 35. Architecture block diagram for organization

4. Conclusions

The systems engineering approach used in this study presents a structured and systematic method that addresses all aspects of the product life cycle and stakeholder needs. Considering the entire product life cycle enables the anticipation of stakeholder needs and allows changes to be made in the early stages of the project where the impacts on cost and schedule are less significant. Besides, taking into account stakeholder requirements throughout the product life cycle permits the development of robust Technical Specifications and ICDs for developers and allows greater satisfaction of these stakeholders.

Additionally, the systems engineering approach used in this work allows not only the product development but also supports the development of both product development organization and other lifecycle organizations. Besides, considering all the organizations involved throughout the product life cycle can lead to the execution of activities in a more efficient and effective way.

The application of systems engineering approach requires a great effort in the correct interpretation of the different variables considered during the process: scenario, context, circumstance, state, mode, function and behaviour. Furthermore, due to the complexity and large amount of information generated in the development process it is recommended the use of an information management software and/or Model-Based Systems Engineering (MBSE).

Finally, this work execution, even with limited scenarios, allowed the understanding of how a modern systems engineering approach can be applied and the advantages that can be obtained from it.

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