Process Development Modeling for CubeSats

Camille Grajauskas Gonçalves[1], Cristiano Vasconcellos Ferreira[1], Xisto Lucas Travassos Junior[1], Eduardo Augusto Bezerra[1], Damylle Cristina Xavier Donati[2], Rodrigo de Oliveira Rodrigues[2], Raquel Viana Pinto Leal[2]
[1] *Universidade Federal de Santa Catarina, Departamento de Engenharia da Mobilidade, Joinville, Santa Catarina, Brasil*
[2] *Universidade SENAI CIMATEC, Salvador, Bahia, Brasil*

Abstract: CubeSat represents a class of miniature satellites with applications in space and academic research, which stands out for its low cost and simplified manufacturing. This work aims to model the CubeSat development process based on the guidelines proposed by the European Cooperation for Space Standardization, using both the knowledge contained in regulatory documents and the knowledge of those working at the SpaceLab of the Federal University of Santa Catarina. The proposed modeling was implemented on the Draw.io platform, a process automation tool. As a result, a structured and systematic methodology was obtained for the stages involved in the development of CubeSats, which aims to contribute to the standardization and improvement of workflows in small aerospace projects.
Keywords: cubesat, modeling, systems.

Abbreviations: BPMN, Business Process Model and Notation. ECSS, European Cooperation for Space Standardization. WBS, Work Breakdown Structure.

1. Introduction

The growing demand for lower-cost and more accessible technological solutions in the aerospace sector has driven the use of miniaturized satellites such as CubeSat. The development of CubeSats by students can begin at different stages, depending on the level of pre-assembly of their subsystems, mission complexity, and theoretical maturity for their development. In any case, the guidelines necessary for their ultimate goal follow the same process modeling pattern as other aerospace products.

Among the recognized guidelines, the niche of Systems Engineering knowledge is identified, which plays a crucial role in ensuring the complete life cycle of a CubeSat. To this end, the European Cooperation for Space Standardization fills this knowledge gap that can be used for the development of CubeSats [1].

Using current literature as the main guide for the construction and launch of satellites in academia, the development process follows a procedure consisting of several stages. However, the search for a visual and systematic way to connect the normative guidelines and supporting documents required at each stage of CubeSat development has been identified. Therefore, it resumes the need for modeling that connects the stages of the guidelines with the stages of the subsystems. [6][7]

Despite the existence of consolidated guidelines for the development of CubeSats, the practical application of these standards in academic environments are often fragmented and dependent on the practical knowledge of the teams involved. The absence of a structured representation that connects the project phases to the required documents and normative guidelines hinders the replication of processes and the training of new members.

Thus, the contribution of this work lies in modeling a CubeSat development process based on European Cooperation for Space

Standardization (ECSS) guidelines and grounded in a real case study, which considers the practices adopted by Senai CIMATEC and SpaceLab. The proposed model seeks to act as an interface between normative theory and academic practice, promoting structured visualization, standardization, and dissemination of knowledge throughout the CubeSat life cycle.

2. Theoretical basis

2.1. Development Process Modeling

Process modeling is the set of activities to be followed to create one or more models of something for a specific purpose. A model can be defined as "a representation (with varying degrees of formality) of an abstraction of reality expressed in a specific type of formalism" [2].

Amaral defines the modeling method as a structured set of elements and rules used to represent specific aspects of a real process or system [3]. This formalism guarantees the product development process because it influences its effectiveness. Modeling methods that reduce complexity and highlight essential aspects contribute to more effective decisions in product development [4].

Models can differ from reality, as they usually represent only selected aspects of a system relevant to the analysis. Therefore, the model must be chosen according to its intended use [2] [5]. This purpose usually involves representation, explanation, specification, analysis, or control of a process or phenomenon [2].

2.2. CubeSat Development Models

2.2.1 ECSS

The European Cooperation for Space Standardization [6] is a unified set of standards for European space projects. These standards are derived from a previous standard (Procedures, Specifications and Standards) that was more prescriptive, required extensive documentation, and favored waterfall and incremental development models.

The evolution to ECSS required the industry to learn from experience gained in using common standards, processes, and models. ECSS has become one of the important sets of standards within the space industry [7].

The ECSS standards were developed jointly by the European Space Agency and the European space industry and include four branches: Management (M), Engineering (E), Quality (Q), and Sustainability (S) [6]. Also, to ensure completeness and correctness, ECSS standards require suppliers to perform different types of reviews: Preliminary Design Review, Critical Design Review, Detailed Design Review, and On-Site Acceptance Test, among many others.

2.2.2 CubeSat

CubeSats were initially designed as educational or technology demonstration platforms that could be developed and launched within one to two years [9, 10]. However, more advanced missions with CubeSats have recently been developed and proposed, indicating that CubeSats have begun to transition from educational and technology demonstration platforms to actual low-cost missions with high potential in terms of scientific return and commercial revenue [11].

CubeSats considerably reduce the cost and complexity of development and launch compared to more robust traditional satellites, which have redundant subsystems, as evidenced by the significant increase in the number of CubeSat launches over the last decade [12].

CubeSats can be of various sizes, all based on a standard unit called 1U. A 1U CubeSat has a cubic shape, with dimensions of 10 cm × 10 cm × 10 cm and a mass between 1 and 1.33 kg. Since the creation of this standard, larger models have been developed, such as 1.5U, 2U, 3U, 6U, and 12U CubeSats. Figure 1 illustrates examples of CubeSats in 1U (left) and 3U (right) formats, with the 3U model measuring 10 cm × 10 cm × 34 cm [18].

Figure 1. (Color online). 1U CubeSat CP1 (left) and 3U CubeSat CP10 (right) [18].

Finally, small satellites have a much lower impact in the event of individual failures, given their relatively low cost and short development time, when compared to larger, more sophisticated satellites, which require budgets in excess of hundreds of millions of dollars [14] and, on average, five to ten years of development [15].

3. Development

3.1 Case Study: Senai CIMATEC and SpaceLab

The need to implement, in a visual and systematic way, connections between the normative guidelines and the supporting documents required at each stage of the ECSS for the development of CubeSats was identified at Senai CIMATEC University, an educational, research, and innovation institution located in Salvador, Bahia. The mission of CubeSat the project is to retransmit meteorological data between CIMATEC ground stations, involving the development of the nanosatellite and the ground station.

In the case study, Senai CIMATEC received direct guidance from the SpaceLab at the Federal University of Santa Catarina, a laboratory that brings together several research and development groups in space systems in general and has missions such as FloripaSat-1, GOLDS-UFSC, and GOMX-5 [16]. The case study dynamics were established through follow-up meetings and analysis of the total processes and stages carried out for the consolidation of CubeSat in the first half of 2025.

In addition to SpaceLab's guidance, Senai CIMATEC started the project with some CubeSat subsystems already purchased, ready for use, without the need for their raw development. From this initial structure, the Senai CIMATEC team focused on integrating the acquired subsystems and planning the remaining stages of development, following the guidelines established by ECSS standards.

3.2 Work Breakdown Structure

Observing Senai CIMATEC's working methods and analyzing the literature on process modeling, the first step is to implement a WBS (Work Breakdown Structure) framework, which is defined by dividing the project into its component elements with the aim of establishing a structure for effective control of the project's scope, schedule, and budget, with the aim of aligning academic and technological practice with European regulations for the development of space systems [19]. The proposed structure consisted of mapping all the stages set out in the ECSS standards, which comprise phases 0 to F, in parallel with the methodology employed by the Senai CIMATEC project team.

This structure was developed using a spreadsheet that organizes the information into specific columns, facilitating the reading and understanding of the workflow and technical responsibility throughout the project. The columns of the WBS were: (1) Phases (0 to F), (2) Product Design, (3) Project Management (focusing on the role of the systems engineer), (4) Documents/Gates, (5) Product Design Tools, and (6) Project Management Tools. This segmentation provided a clear view of the relationship between ECSS regulatory requirements and institutional practice, allowing for greater traceability and control of the activities carried out.

In addition, the need for a breakdown by subsystem was identified, since the development of a satellite, even in its CubeSat version, requires an integrated and systemic approach. To this end, the main subsystems present in space missions were considered, namely: Payload, Communication Systems, Power Systems, On-Board Computer (OBC) System, Thermal Control, Propulsion System, Launch System, Attitude and Orbit Control System, in addition to the Structural Design. Each subsystem was assigned the specific tasks required in each phase of the ECSS cycle, considering everything from feasibility studies (phase 0) to operation and disposal (phase F).

The segmentation of each phase into smaller, specific tasks allowed for a more granular understanding of the necessary activities, which directly contributes to the planning, management, and control of the project. The construction of this WBS was based both on practical experience observed at Senai CIMATEC and on official ECSS documents, their appendices, and complementary publications, as in the example in Figure 2 and Figure 3.

Figure 2. Processes in phase zero for subsystems in the CubeSat Development Process within the WBS structure. Authors, 2025.

STEPS			Work Breakdown Structure – SYSTEMS								
PHASES		PRODUCT PROJECT	PAYLOAD	COMUNICATION SYSTEMS	ENERGY SYSTEMS	ONBOARD COMPUTER SYSTEM	THERMAL CONTROL	PROPULSIO IN SYSTEM	LAUCH SYSTEM	ALTITUDE AND ORBITAL CONTROL SYSTEM	STRUCTURAL DESIGN
PHASE 0: Concept Studies	1	Identify any initial customer requirements or scope of work, which may include: mission, sciente and top-level system.	Identify the general requirements associated with the payload system. Determine the purpose of the payload, such as scientific data collection, remote monitoring, communication, or technological experiments.	Identify whether you need telemetry and/or remote control and the type of antenna. Check whether you need a Ground Station.	Analyze the initial forecast for solar panel square footage and battery quantity.	Use a percentage value from the project as a reference.	Use a percentage value from the project as a reference.	Check whether it is necessary or not.	Check whether it is necessary or not.	Check whether a note is needed (active control) or not. Use a percentage value from the project as a reference (passive control)	Analyze whether the CUBESAT will have 1U, 2U, 3U, or more.
	2	Identify and involve users and other stakeholders.									
	3	Prepare the project proposal, which includ mission justification and objectives, WBS (Work Breakdown Structure) and Technology assesment and maturation strategies.									
	4	Satisfy MDR entrance/sucess criteria									

Figure 3. Processes in phase zero for management requirements in the CubeSat Development Process within the WBS framework. Authors, 2025.

MANAGEMENT			
PROJECT MANAGEMENT	GATES	Product Design Tools	Project Management Tools
Develop preliminary SEMP (System Engineering Management Plan) / Preliminary Project Requirements.	MDR - Mission Definition Review release the mission statement and assess	Needs assessment questionnaire; Standard requirements list; Scenario constraints; Benchmark.	Scope management (internal and external), time (time chart), costs (investments and sources), procurement (schedule), risks (technical and managerial), and integration.

3.3 Business Process Model and Notation Modeling

Following validation of the spreadsheet with stakeholders the visual modeling stage of the process began. For this, Draw.io was used, an online diagram modeling tool with direct integration with Google Drive. This choice was made due to the tool's flexibility, accessibility, and adherence to international process modeling standards.

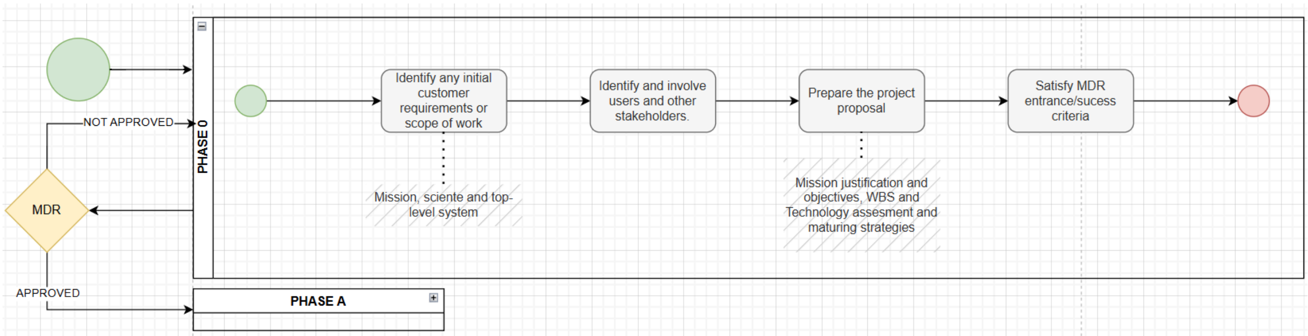
The modeling was performed using the official Business Process Model and Notation (BPMN) notation, which, according to White, is a recognized standard for the graphical representation of business processes. BPMN aims to provide a notation that is understandable to all involved through standardized symbols and a clear visual structure. The main elements of BPMN include Pools, Lanes, Tasks, Gateways (decision points), Events, and

Connectors, which together structure the logical flow of a process.

In the model, each Pool was used to represent a phase of the ECSS development cycle, functioning as a container for macro-activities conducted at that stage. The pools function as the main divisions of the process and can represent major participants or specific phases, as adapted for this project. Within each pool, tasks corresponding to the macro stages identified in the previously developed WBS spreadsheet were inserted. Each task was represented by an activity block, symbolizing specific actions performed by the team during that phase.

Gateways, represented graphically by diamonds, were inserted to indicate critical decision points in the process. In the context of CubeSat and ECSS standards, these gateways were used to represent mandatory verification moments, such as reports and formal validations required by the standard, for example, the Preliminary Design Review (PDR) and the Critical Design Review (CDR). Thus, each gateway signaled a fork in the process, whose next path would depend on the approval of normative deliverables. Figure 4 represents phase zero of the CubeSat development process to illustrate the process, it is the visual way to see Figure 2.

Figure 4. BPMN for phase zero of the development process made in Draw.io. Authors, 2025.



3.4 Model Validation

With the modeling completed using the spreadsheet (WBS) and the BPMN diagram in Draw.io, a validation process was conducted with the stakeholders directly involved in the project: SpaceLab/UFSC and Senai CIMATEC. The objective was to assess whether the products developed corresponded to the real needs of the CubeSat development process and whether they contribute to clarity, organization, and alignment with ECSS standards.

During validation, it was identified that both the spreadsheet and the BPMN model offer benefits for understanding and managing the process. Although the proposal is not unprecedented from a methodological point of view—given that there are several ECSS tailoring initiatives applied to CubeSat projects—the combination of visual modeling with the analytical structure, applied to the specific case study of Senai CIMATEC, proves to be effective. The clarity provided by the model allows even teams still in formation or unfamiliar with ECSS to understand what phase they are in, what deliverables are expected, and what critical decisions need to be formally validated.

This structure has also proven useful for SpaceLab, which frequently conducts training and supports other institutions in adopting practices related to space systems engineering. Although SpaceLab already follows ECSS guidelines, it was identified that the absence of a didactic and systematized model hinders the replication and standardized teaching of the process. Thus, the proposed model meets both pedagogical and operational needs, providing a visual and adaptable reference.

From a more technical point of view, the main gain lies in the possibility of more accurately mapping the critical reviews provided for by ECSS (such as PDR, CDR, and QR) with the associated appendices and normative documents, as well as with the subsystems involved in each stage. This makes it clearer, for example, what information from the subsystems should be included in a technical report for approval at a given gate, ensuring greater adherence to the European standard and reducing the risk of documentary omissions.

However, one area for improvement was identified: the BPMN modeling does not cover the development processes of the subsystems listed in the spreadsheet. Although the spreadsheet provides details of the activities per subsystem in each phase of the ECSS cycle, this level of granularity was not incorporated into the Draw.io diagram. This limitation represents an opportunity for future iterations of the model, aiming to integrate the functional perspective of the subsystems with the procedural logic of BPMN, which would further expand the practical application and teaching potential of the proposed model.

4. Conclusion

The proposal arose from the need to clarify the relationship between the phases of a satellite's life cycle, the mandatory deliverables, and the subsystems involved, especially in environments where practical knowledge was still under development, as in the case of Senai CIMATEC.

Validation with the Senai and SpaceLab teams showed that the model, although not unprecedented on the international scene, was well suited to the reality of the case study. It facilitates understanding of the project stages, helps to locate where the team is in the cycle, and shows more clearly which documents and decisions are required at each phase. It also stood out as a useful tool for training and standardizing future processes.

The main contribution of the model is to serve as a bridge between normative theory and applied practice, allowing for a better visualization of what each ECSS revision requires in terms of subsystems and documentation. As a point for improvement, it should be noted that the subsystem development processes described in the spreadsheet have not yet been modeled in BPMN, which can be explored in future work.

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