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Model Based Systems Engineering
applied to Small Satellite Systems

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Alla mia famiglia,

il mio inesauribile propellente.

"[…] Tutto questo è parte di un duro lavoro. Ho lavorato a lungo per tanto tempo e, sapete una cosa, non si tratta di vincere. Ma si tratta di non arrendersi. […] E non si tratta di quante volte siete stati respinti, siete caduti o siete stati sconfitti. Si tratta di quante volte vi siete rialzati e siete stati coraggiosi ad andare avanti."

Lady Gaga

Abstract

This thesis aims to evaluate the potential advantages achievable by the application of the Model Based Systems engineering to the System Engineering of PLATiNO programme, in particular to the requirements engineering tasks.

After a research-based survey between the MBSE existing languages, SySML (Systems Modeling Language) and OPM (Object-Process Methodology), the choice has fallen on the latter one.

The willpower to investigate the OPM approach was dictated by its characteristics of simplicity and immediacy which seemed to fit better PLATiNO features. The OPM related tool OPCAT has been used in order to realize a different representation of the technical requirements and of the mass budget of PLATiNO platform.

This work shows that OPM diagrams might be useful in order to unify in a single modality different PLATiNO System Engineering activities.

SOMMARIO

Il lavoro svolto mira a valutare l'utilizzo dell'approccio OPM, relativo alla filosofia dell'"Ingegneria di Sistema basata sul modello" (MBSE), al sistema satellite PLATiNO 1 facente parte del Programma PLATiNO in cui l'azienda SITAEL è coinvolta.

La tesi si articola in sei capitoli: il primo capitolo si propone di rendere noto il contesto di collocazione dell'analisi condotta, definendo le motivazioni di partenza che ne hanno plasmato le basi e le domande a cui il suo sviluppo ha puntato a fornire risposta. Il secondo capitolo è un'introduzione ad alcuni concetti di base, riguardanti l'ingegneria di sistema in generale e la nuova filosofia MBSE. Nel terzo capitolo si esplicita l'approccio utilizzato: dopo un confronto tra due dei linguaggi di modellazione dei sistemi, SySML (Systems Modeling Language) a OPM (Object-Process Methodology), si valuta ragionevolmente la scelta di OPM come mezzo di applicazione dell'ingegneria di sistema basata sul modello al sistema satellite PLATiNO 1. Viene, inoltre, presentato lo strumento digitale che ha reso possibile l'utilizzo dei concetti di OPM al sistema in esame, ovvero OPCAT. Il quarto capitolo contiene il nucleo del lavoro, ovvero la costruzione pratica di alcuni diagrammi relativi al sistema in questione, ascrivibili a due aree delle attività dell'ingegneria di sistema per come esse vengono individuate secondo l'ECSS (European Cooperation for Space Standardization): ingegneria dei requisiti e parte di configurazione progettuale. Nel quinto capitolo si esprimono le deduzioni che è stato possibile ricavare a valle dell'analisi: esse hanno fornito una risposta soddisfacente, sebbene non positiva su tutti i fronti, alle domande di cui a primo capitolo. Il sesto ed ultimo capitolo riassume le conclusioni tratte a lavoro terminato e fornisce alcuni spunti per sperimentazioni ed approfondimenti futuri.

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1. PREFACE

Nowadays, space systems are experiencing an increased level of complexity in terms of the amount of variables and data. It became difficult to face this complexity with the traditional SE approach: space products are not conceived, designed and realized in the same place and the project requires several people involved in. The design exhibits a multi-objective and multi-domain nature and needs the synergic effort of several companies and industries placed in several countries which are characterized by different languages but must communicate in order to realize a working product within the established deadlines. For these reasons, natural language, closely related to each country, is not the best solution to describe space systems. Moreover, even if verbal descriptions are supported by diagrams, sketches and tables, they produce a huge amount of documents that requires time to be read and understood.

Up until few years ago, the main characteristics of a systems, that is structure (forms), function and emergent behaviours (interfaces), have been expressed in the form of sentences as well as constraints and drivers. At most, technical requirements were displayed in the specification tree, but the inputs of the process to derive them, were list in a textual form. In this context, the big picture of the model has blurred and fuzzy outlines. In order to read pages of system description and trying to understand them, the overall conception is lost: a lot of time is spent to untangle the many references to previous or following pages or other issues. Each phase of the development of the product is affected by the dispersive documental approach which complicates the already complex system expanding the time of realization.

Moreover, the document-based approach makes difficult the communication between the companies involved in the project because of the fragmented nature of the textual description modality. In fact, space complex systems are not developed in the autonomy of a single company, but each company gives its own contribute to the design and then the SE works to ensure that all elements fit well with the whole system.

In such a context in which the traditional documental approach is becoming the past, companies are interested in the evaluation of a different SE approach in order to optimize the communication among the working groups. MBSE seems to fit this requirement and, in particular, OPM might be a good means of communication and system description. The management of the development of the system might be realized by a visual formalism and equivalent textual sentences as allowed by this modern methodology. For this reason, the research is moving towards the direction of the globalization at the same pace of modernity in terms of need of speeding times and simplifying where possible, starting from easy concepts for building complex systems.

The main questions that gave rise to the analysis presented in this work can be explained as follows:

- Is it possible to apply a new standardized methodology to a modern complex system in order to reduce SE documentation?
- How much does the used approach represent a step forward for the digital twin of the system as a single source of truth?
- How is it possible to replace, completely or partially, the SE activities with a single digital model which can explain structure, behaviour and functions of the system?
- As far as is it possible to go with this "conceptual model approach" in the product life cycle phases?

In theory, Professor Dov Dori proposes the Object-Process Methodology with the purpose of building a mental picture of the global system. The new MBSE methodology aims to convert the "tacit knowledge" of the documental approach to "explicit knowledge" of non-verbal means in an unambiguous representation.

Therefore, the technical question which propelled this work has been if OPM would be the right choice to describe a complex system and, if yes, up to what level of decomposition this approach would work.

Starting from the driving previous questions, the experimental analysis was carried out in order to achieve the following objectives:

- To verify the technical feasibility of the use of OPM approach in order to reduce the SE documentation for describing PLATiNO 1 satellite system.
- To validate the benefits of using OPM as a potential substitute of the document-based approach of SE.
- To investigate at which level of decomposition the OPM solution may be used for simplifying concepts.

The next chapter of this thesis delves into the main concepts of the Systems engineering and of the more recent philosophy of the Model Based Systems engineering. The chosen analytical approach, that is OPM, is explained into the third chapter. The fourth one represents the fundamental core of this work because it introduces the case study taken into consideration and shows the actual analysis carried out with OPCAT tool. The discussion of the results is contained into the fifth chapter, whereas the last one displays some final considerations and some ideas for future studies.

2. Introduction

2.1 SYSTEMS ENGINEERING

2.1.1 Overview

In order to understand the "relatively recently born" approach of systems engineering, it is necessary to give a justified definition of the word "system".

A system is a collection of different elements that return results not obtainable by each part alone. So the key point of the definition of a system is represented by the interconnections among the elements of which it is made up of. These elements are related in such a manner as to accomplish a function to satisfy identified needs. The value of the system is higher than one of its parts considered as alone; in fact, it is given by the sum of the value of the single element and the relationships among the elements [1].

The discipline known as "systems engineering" plunges its roots in the project of the progenitor of main-line railway motive power, the Rocket locomotive (1829).

In the 1962 Arthur David Hall signed the story of this science with the publication of "A methodology for System engineering".

When, in 2002, the international standard ISO/IEC 15288 was introduced, the discipline of systems engineering was officially recognized as the best mechanism to realize a product or a service considering costumer requests and supplier constraints [2].

Systems engineering is an approach which involves different branches of engineering (structural, electrical, telecommunications, etc.) which aim is to deal with complexity and manage the interconnections among the parts in order to realize a successful working system satisfying the most of customer needs. It is an iterative process in which contradictions between feasibility and desires are detected and compromises reached.

In order to ensure the achievement of the project goals, System Engineers work on two fronts: the management of costs, schedules and the technical system behaviour; the technical processes which involve the specification, design and verification of the product. Both the parts contribute to achieve the system objective mitigating the risk. In this sense, the most important activities could be summarized in:

- Understand and analyse stakeholder needs

- Specify system
- Synthetize alternative system solutions
- Perform trade-off analysis
- Maintain traceability

The first phase is thorny and complex, and its correct development is fundamental for a successful outcome of the project. Once established the right direction, functions of the system must be defined and then we proceed with the design of components and their test in order to gradually determine the system specifications of lower levels. Therefore, the final solution is obtained in an iterative way moving from the shallowest level to the deepest ones [3].

Michael Ryschkewitsch and Dawn Schaible of the National Aeronautics and Space Administration, in the paper "*The art and science of System Engineering*" (2009) describe an enjoyable comparison in order to put in evidence the suitable characteristics that a system engineer must embody, in the opinion of NASA best technical minds on the subject. The subject is the system which can be seen as a symphony. The actors of the discussion are the maestros of the orchestra, who lead the musicians to resolve their music into the whole opera in a great way, and the system engineer who can see in his mind the final shape of the design and lead the team to achieve it meeting the system requirements [4].

2.2.2 Why do we need Systems engineering?

Thinking in terms of System as a whole requires processes of diagnosis, learning, modelling, discussions and definition of framework. The role of SE is revealed not only in the context of the system design, but also in that of interactions of the system with the external environment. So not only the interfaces between the single parts of the system must be curated, but also those between the system and the outer world. In the last few years, the need of SE has become more important due to the shortening of the time of the delivery of a new product: the recent technological progress has brought industries to accelerate the process of building a product in order to become an actor of the market as soon as possible without dropping in quality. In this scenario SE results very helpful because of its developed processes with which the technical design is realized: the management of requirements, realization in team, test and risk analysis lead to the construction of an efficient product in a reduced time due to the possible timely intervention on each phase of the development [5].

SE for a project can be thought as a roundabout realized for replacing a complex and dangerous crossroad: a lot of tragic incidents are avoided, it is easy to understand who has the right to engage the intersection first and traffic flows better.

The most important objective of the SE is to guarantee that the global system fits with performance, costs, risks, schedule; so it attempts to find project solutions which can provide the best combination of cost and effectiveness through the trade studies.

As Beni Suranto writes in the article " *System Engineering: why is it important?*", SE is a primary need for the project and a powerful tool able to face " the three evils of engineering": complexity, lack of understanding (of the relationships within elements or of the objectives of the project) and communications problems (inside the team or between customer and suppliers) [5].

Each project is different, so sometimes it is appropriate to achieve the most effectiveness possible maintaining a fixed budget and a fixed degree of risk. Other times, it is necessary to reduce the cost at minimum possible at fixed effectiveness and risk. In this sense the *SE Nasa Handbook* talks about "The System Engineer's Dilemma": in order to reduce cost maintaining constant the risk, performance must be reduced; reducing cost maintaining constant the performance means to accept a higher risk; in order to reduce the risk at constant cost, performance must be reduced; reducing risk maintaining constant performance means to take in account a higher cost [1].

Furthermore, it has been demonstrated that the "demonstration and validation" is the phase of the life cycle that requires a fast increase of the costs of the project, as shown in Figure 1 [6].

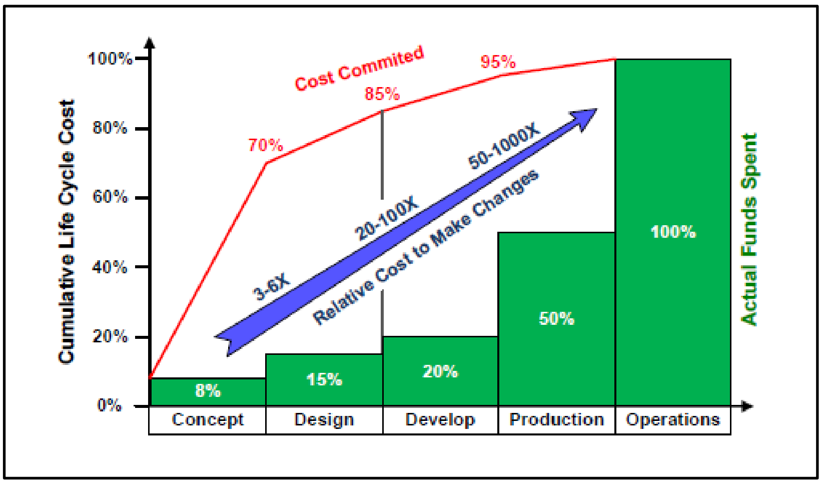


Figure 1: cumulative percent of life-cycle cost as function of system life-cycle [6].

2.2.3 Inside SE

The benefits of SE are evident when the phases of the program and project life cycles are considered. The development of the phases of the project life cycle allows to get sub-products step by step (as results of each phase), adding more and more details, in order to achieve the final global product.

This scheme involves several phases in which SE moves from a high level to a lower one fighting with requirements, risks, costs, simulations, realization and validation of the project. In this sense the SE faces with complexity and manages it in a dynamic optimized process of analysis.

Usually the Vee model is used to define the activities typical of each life cycle stage. It is the graphic representation of the sequence of steps to be taken in systems development lifecycle. It describes the activities to be performed and the results that have to be produced during product development:

- The left side of the V represents the initialization and decomposition of requirements and relation of system design
- The base of the graph represents the actual implementation of the system (production)
- The right side of the V represents the integration of parts and their validation up to operations and disposal [7].

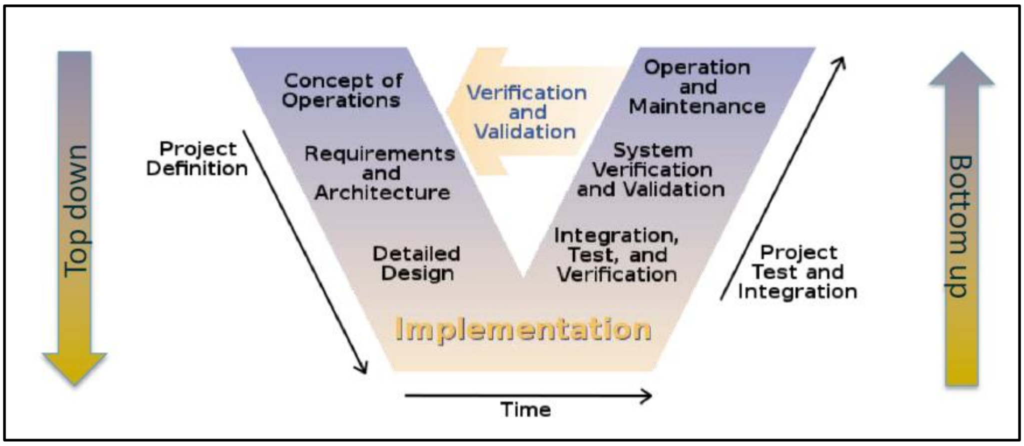


Figure 2: V-model example [7].

Each step of the V involves technical processes without which the risk of the project failure would be unacceptably high. These processes lead to the creation of a full set of requirements which allow to meet the desired characteristics respecting the performance, environment, external interfaces, and design constraints. Technical processes enable system engineers to manage the relationships between engineering specialists, stakeholders and manufacturing.

2.2.4 Space Systems engineering

Systems engineering as an approach to the design, spans as fascinating as the Space field may be, it has always represented a sequence of challenges for Engineering due to the complexity of systems which belong to it. Space systems, in fact, must perform their tasks in an environment quite different from that found in Earth surface; they really exhibit a wide number of subsystems interactions, involve a lot of people and domains, require high reliability. For these reasons, to obtain the best possible space product, it is necessary curating the optimization of ever new methodologies which results strategic in the management and organization of the system design. Therefore, building a space system implies to manage correctly its product life cycle (PLM) [3].

As summarized by Figure 3, the processes of a space system design are connected by recursive relationships and they are essentially four: stakeholder analysis, technical requirements, logical decomposition and design solution [1].

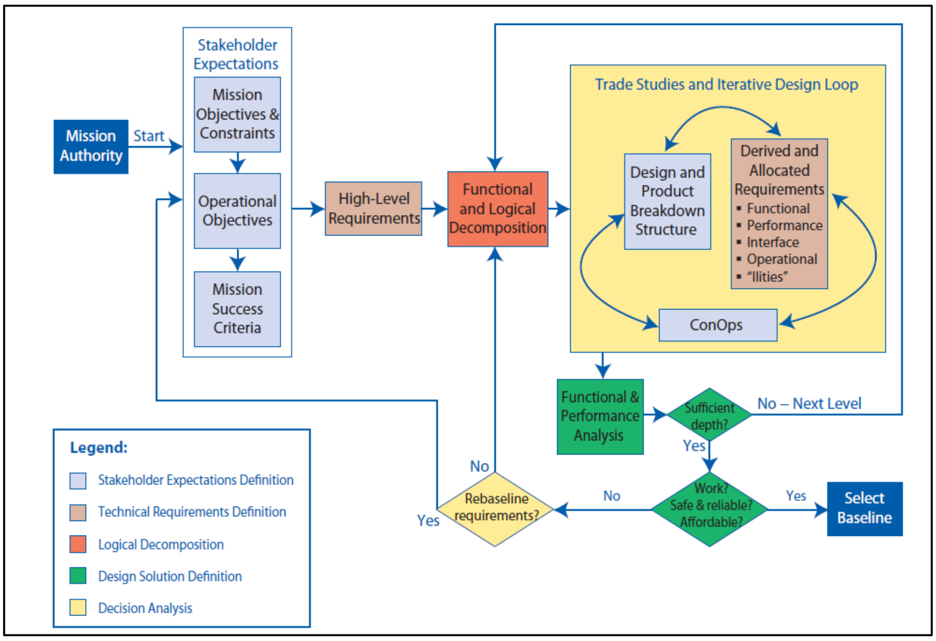


Figure 3: processes of space system design [1].

In order to evaluate the project status step by step, the writing of reports and documents follows each milestone or key decision point of the main phases of the design. These documents are very important because they allow to keep under control the development of the system for each level, highlighting opened issue and results of performance analysis [3].

2.2.5 European Space Systems: ECSS

As we have already discussed, complex space systems require several people, domains and processes; so, to manage all the several perspectives involved, it is necessary to develop a set of rules to level out them. Operating in this sense, the European Cooperation for Space Standardization (ECSS) organization put efforts to coordinate the standardization activities in Space sector. This initiative of providing a common design direction captivates a lot of agencies and companies.

Until 1993, when ECSS was born, space standards were no uniform and this resulted in less cost-effective products. Starting from Autumn of that year with the publication of the document "Standardization Policy", which reported ECSS objectives, policies and organizational standard, members rounded up in a synergic work in order to provide a set of common rules to guide all the European Space projects. The purpose of ECSS is that of continuing to update standards with better methods and procedures, optimizing design work. This must be done taking into account the positive and negative issues revealed by past projects. Due to the international nature of Space Engineering, ECSS standards should not contradict those of other countries of the world.

The aspects considered in ECSS documents are:

- Project management
- Engineering
- Product assurance
- Space sustainability

At the will of space agencies and industries, ECSS standards documents are accessible to the public and are made in such a way to guarantee the users and customers approval.

Among the members of ECSS we can include the European Space Agency, industry, governmental and scientific organization.

According to ECSS, the product life cycle management process can be made explicit in the following shape [3]:

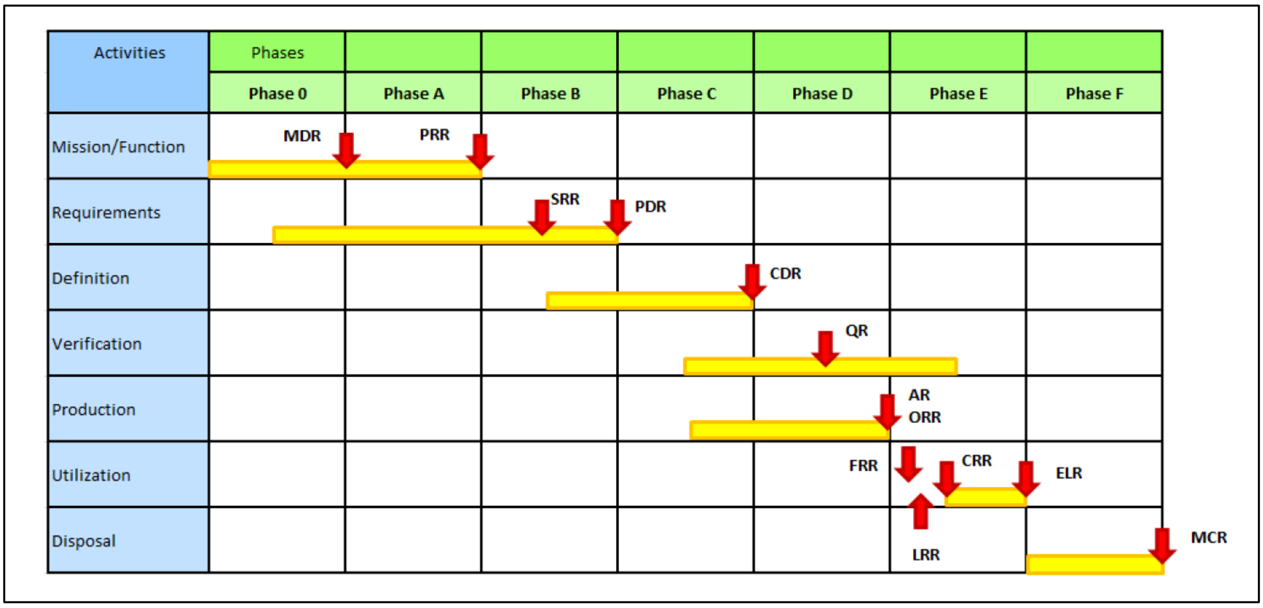


Figure 4: PLM according to ECSS [3].

2.2 MBSE PILLARS

2.2.1 An innovative perspective

The expression "Model-Based System Engineering" dates back to 1993 when it appears for the first time as the title of a book. However, this doesn't surprise us as in the late 1990s and early 2000s the document-based systems engineering vision disclosed its faults: it was waste of time writing the documents, reading them to validate the contents, verifying the correspondence between them and the realized product. Moreover, the increasing complexity of the systems, made widely clear the inefficiency of this methodology. Documents include a lot of specifications and guides which need to be validated by humans. Consequently, it results too expensive or too error prone even if we think that textual requirements often result contradictory. Drawings of system operations lead to misunderstandings among engineers.

For these reasons, it was thought about replacing the Document-Based systems engineering with MBSE. But this intent didn't actualize until 2007, on the occasion of the INCOSE Systems Engineering Vision 2020. It defines MBSE as "*the formalized application of modelling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases.*" (INCOSE-TP-2004-004-02, Sep 2007). The reason for the existing gap of "silence" between 1993 and 2007 could be the same that leads engineers involved in the space missions to choose technologies widely tested in place of the new one tested less than the other ones at the time [8].

MBSE distances itself from the Document-Based SE in terms of:

- Way of displaying information: in Document-Based information are reported mostly as text or *ad hoc* diagrams; moreover, they are often redundant and repeated in different sections of documentation. In MBSE based, information are both visual and textual; constructs are built once and reused; diagrams contain consistent notation.
- Measure of changes impact: in Document-Based approach, the impact of change spans across different documents because often they are displayed only in the textual form, isolated from the rest of the structure and behaviour. In MBSE approach, relationships define traceability paths; the changes are automatically propagated to all parts of the project.
- Measure of integrity- completeness, quality and accuracy: in Document-Based vision, that is realized by manual inspection. In MBSE it is programmatically automated [9].

Every product is the result of an iterative process in which different system solutions are evaluated as long as the better one is achieved in terms of stakeholders satisfaction and constraints respected. The final system derives from a suitable net of object relationships. The research of the best solution is characterized by the necessary management of procedures, budgets, reviews, and so on. It is easy to understand that the more complicate the system becomes, the more difficult is to monitor its development, taking into account that an initial oversight can turn into a big problem when project is finished or is about to be.

MBSE promises to increase the efficiency of the management of the system life-cycle, even because it allows a continuous simulation of the functioning of the system itself. Therefore, this approach is a reason of interest in the world of Space System Design. If we consider, for example, the definition of the requirements of a complex system, their traceability results very difficult in a traditional approach in which they are written in a textual form on a lot of documents. This makes productivity lower in the best case; in the worst one, product presents some failures which are detected only once it is already in customer hands.

Moreover, in the Document-Based approach the generation of reports requires time because there is not a tool which derives them from the design analysis in progress. The maturing environment of the project and the required documents are detached. Rather, MBSE methodologies allow to make this process to be automatic because the system model diagrams contain and store all the information relating to each specific phase of the development of the system. The documents needed are "extract" from system model information by processing data through some scripts which respect the indications of a pre-set template. In this way documentation is directly linked to the design working environment, namely the model. This supports the global coherence of the design thanks to the fact that the same element of different diagrams indicates the same thing. Moreover, engineers can focus more on modelling rather than on the drafting of documents [3].

2.2.2 The MBSE potential

Nowadays the market is populated by customers who pretend that a product must be cheaper, works better and is made faster. For this reason, in all engineering sectors (Space included), industries and companies must keep up with the times: design time must be shorter, quality improved and complex systems made affordable. The logic of MBSE seems to embody the right answer to these needs. In fact, it results a valid work instrument for obtaining a guided characterization of the input data: the system is modelled on the basis of precise rules and specifications, avoiding the potential definition of wrong objects. This allow us to easily detect possible violations of constraints, find a suitable solution and quickly modify the rest of the design by power of that solution. Therefore, by following the MBSE approach, several benefits can be list: stakeholders may communicate better, the development of the risk can be controlled, quality of the product gets better, productivity increases, spread of knowledge enhances, sources management improves. Moreover, the possibility to simulate system behaviour step by step following its development and instantaneously detecting failures and correcting them, allow us to save money [3]. As the following picture shows, the phases of the system life cycle which are more expensive are those related to the integration test and operational test [10]:

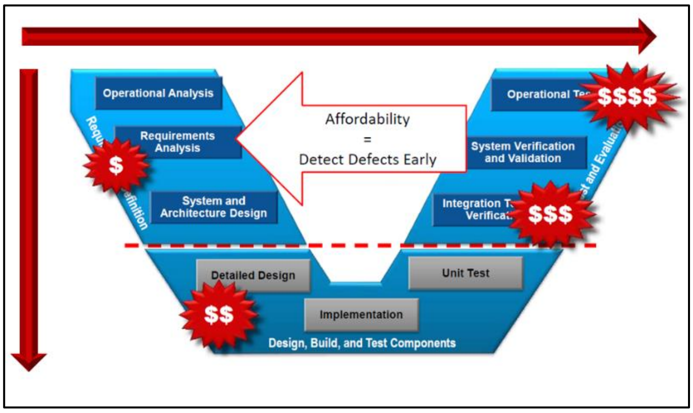


Figure 5 most expensive phases of lyfe cycle [10].

But, early detecting defects by the use of models simulations, means that the product will be affordable and companies will increase their competitiveness.

Aware of the potential improvements that the adhesion to MBSE vision can bring to the world of Systems engineering, the International Council of System Engineering (INCOSE) promotes its development scheduling the main goals and improvements that might be achieved in the future, as the following roadmap proves [3].

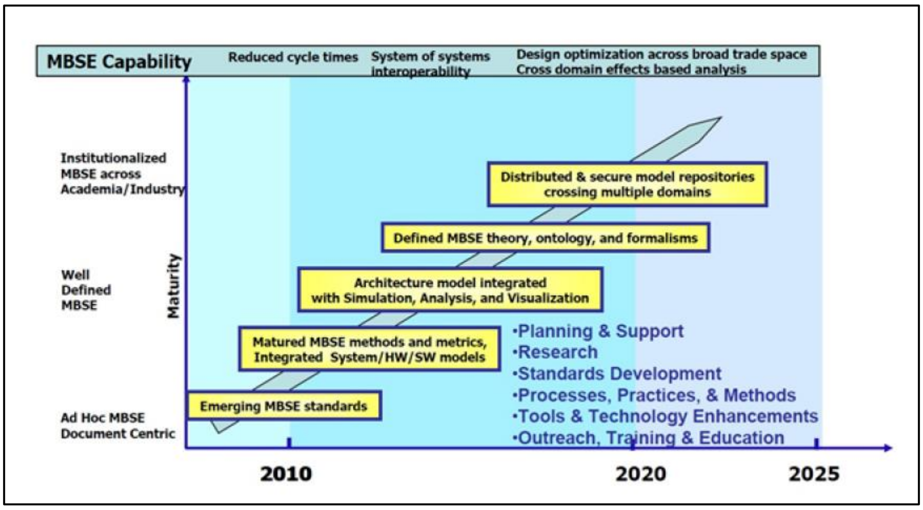


Figure 6: MBSE INCOSE roadmap [3].

2.2.3 Inside MBSE

Before getting into the topic of MBSE, it is necessary to clarify the terminology looking at the definitions given by INCOSE MBSE Focus Group [11]:

- A process defines WHAT must be done in order to achieve an objective; it carries out in a list of tasks logically related which can be applied at different levels of analysis.
- A method defines HOW the tasks must be realized; it represents the technical approach used to perform the task. It is important to note that the How at a level of abstraction can be the What at the lower level because a method is the process used to perform the How.
- A tool is an instrument which facilitates the implementation of the How improving the efficiency of the method.
- A methodology defines a way in which processes, methods and tools must be applied and related in order to solve a problem.
- The environment represents the surroundings of the system, everything which is external to it, but which influences it setting conditions and limitations; so it has the power to enable or disable some "what" or "how".

In this context, we will focus on the MBSE vision defining a "model" as a simplified version of a system obtained by a graphical or mathematical representation. In other words, it is an abstraction in which reality results stylized in its minimal components. The model is useful for facilitating the understanding; for quickly examining "what if" scenarios; for explaining, controlling and predicting events [10]. For these reasons, models increase the efficiency of managing complexity by supporting concurrent teams, supporting the impact of changes analysis (traceability), incrementing iterative and parallel processes. In this sense, a "system model" is a structured representation that focuses on the system in terms of:

- Requirements: what are stakeholders objectives and success conditions of the system.
- Behaviour: functions of the system, modes of operation and what the system must perform in order to achieve mission objectives.
- Structure: the parts involved to accomplish the goals.
- Properties: constraints, limitations, physical characteristics.
- Interconnections: communicative relationships between structural elements necessary to achieve the right performance under the imposed constraints [9].

So the aim of MBSE is to formalize the processes and the methods involved in the development of the system, through the use of models. In order to apply this formalization, as reported in SysML Distilled, three "pillars" (as the author calls them) are needed [12]:

- A modelling language: just as a phrase can be formalized and formulated differently depending on the language used, model formalization is realized by the use of a semiformal language that defines the type of elements which the model must be composed of and the allowed relationships between them. Model languages are divided into graphical ones (such as SySML, UML, UPDM, BPMN, MARTE, SoaML, IDEFx) and textual ones (such as Verilog or Modelica).
- A modelling tool: once we have chosen the suitable modelling language, in order to obtain a clear and universal shape of the model, we can implement it making use of a tool.
- A modelling method: a system model is created by a modelling team that performs specific tasks.

3. APPROACH

3.1 MBSE languages: SySML and OPM

Languages arise from the need to describe something and communicate it to others. In particular, MBSE languages aim to describe a system in such a manner that: all people involved have the same perspective by which exchange information; it is easy to create semantic links between systems or to preserve and reuse knowledge. Until now, to describe systems, we used documents which are sets of descriptions realized using common words of the natural language (i.e. English, Franch,…) and graphical elements (sketches and drawings). All this information needed to build and operate a system are contained into the Technical Data Package (TDP): when a new system is built, a TDP is produced; it is the deliverable from design process. With the increase of the levels of decomposition needed by modern complex systems, it is easy getting errors, omissions, different interpretations of these information. It has become necessary to describe systems much more precisely [13] and heading towards a model-based approach. In fact, a system is represented in textual and visual modalities by a System Modeling Language (SML). A successful model construction is subordinated to a great choice of the suitable SML. MBSE provides several alternatives of languages, two of the several ones are SysML and OPM.

The Systems Modeling Language (SySML) has its roots in the Unified Modeling Language (UML). The latter is largely used in Software Engineering, so its taxonomy and ontology are oriented towards that direction. Therefore, several problems arise by adapting this language for system modelling: for example, UML diagrams cannot fully express the physical characteristics and components of a system. For this reason, in order to decline UML on systems engineering, the OMG (Object Management Group) System Engineering Domain Special Interest Group (SE DSIG) was established. At that point, this group, INCOSE and ISO AP 233 workgroup worked together to create the basis for a modeling language. In March 2003 the OMG gave out the UML for System Engineering Request for Proposal (UML for SE RFP) to which SySML was the obvious answer to RFP. In fact, its version 1.0 was adopted by OMG in March 2006. SysML preserves some characteristics of UML from which it derives and adds some extensions in terms of diagrams in order to describe the various aspects of the system. In addition to them, this modelling language provides the means to relate the model elements. SySML is characterized by nine diagrams which explicate four "pillars": structure, behaviour, requirements and parametric relationships. These nine diagrams are grouped into four types of structure diagrams, four types of behaviour diagrams and a requirement diagram. In particular, SySML provides two new types of diagrams respect to UML: Requirement Diagram and

Parametric Diagram; moreover, it modifies three existing diagrams: Block Definition Diagram, Internal Block Diagram and Activity Diagram and reuses the last four diagrams gleaning them from UML without change anything. About the four pillars in detail:

- Requirements: it is the great innovation of SySML. System requirements are represented starting from the text-based modality and they relate to other model elements. A basic requirement is made up by a unique identifier and text properties. The requirements diagrams can assume different shapes: graphical, tabular, tree structure; they can also belong to other diagrams highlighting the relationships with other model constructs. Typically, SySML requirements constructs aim to integrate system requirements with other parts of the model; so, they cooperate with the external requirements management tools. SySML focuses on requirements among relationships: requirements hierarchies, source-derived requirement dependencies, satisfaction relations between requirements and the model, and verification dependencies to test-cases.
- Structure: the basic unit in SySML structural aspect, is the Block. It can be used at any level of the system decomposition, from the single components up to the top-level system. In particular, two types of structural diagrams exist: the Block Definition Diagram and the Internal Block Diagram. The first one shows system classifications and levels of decomposition, that is it focuses on the relationships among blocks, such as dependencies or generalizations. The latter describes the internal structure of a block showing block properties and connectors between properties. Moreover, SySML has another structural diagram available deriving from UML, which is the Package Diagram that is used to organize the model by grouping model elements.
- Parametric: this type of diagram is an exclusive prerogative of SySML. It expresses the relationship between constraints (equations and inequalities) and the properties of a system. Parametric diagrams serve engineering analysis in terms of performance of the system, reliability, availability, power, mass and cost. These diagrams are also used to support the trade studies of candidate physical architectures.
- Behaviour: SySML provides four types of behavioural diagrams [14].
    - Activity diagram focuses on the flow of control and the sequence of actions that transform inputs into outputs. Usually this type of diagrams expresses the desired behaviour of the system.
    - Sequence Diagram focuses on the interactions among the parts of a block via asynchronous signals or operational calls. This type of diagrams is used for specifying

test cases as well as for specifying a behaviour as an input to the development stage of the life cycle.

- State Machine Diagram focuses on the set of states of a block and the potential transitions between those states when a particular event occurs.
- Use Case Diagram focuses on the services that a system performs in collaboration with its actors. The main aim of this type of diagrams is to define the relationships of the involved entities in reaching some targets [12].

Next figure provides a graphical taxonomy of SysML diagrams:

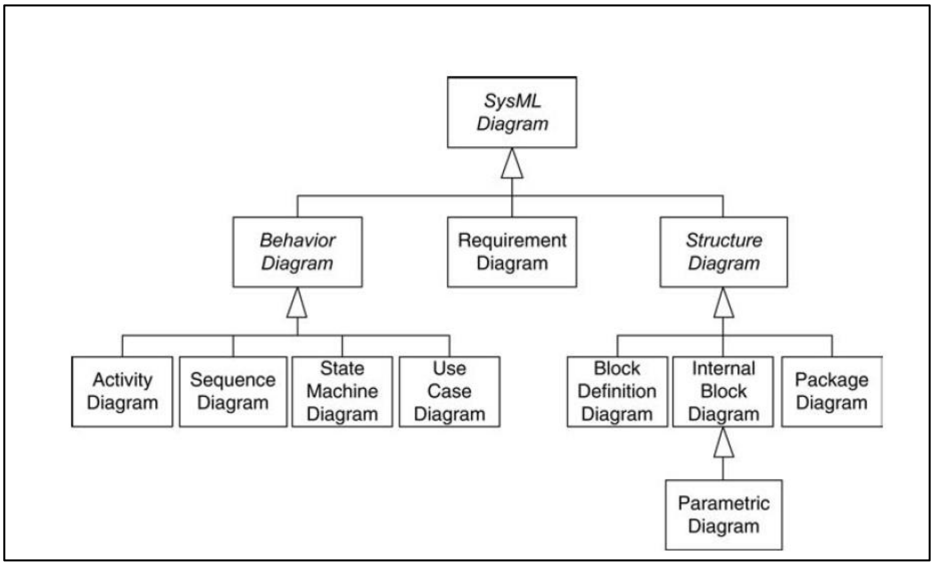


Figure 7: SySML diagrams [12].

Therefore, SySML is a standard and general purpose modelling language for modelling systems. It is not associated to a particular method: SySML only provides a vocabulary, but it does not specify when to use a concept or another, how to organize models, etc.. Inspired by SySML concepts at 75%, Arcadia method and the related tool Capella, focus on the design of systems architectures. The main difference between Arcadia/Capella and SySML concerns the functional analysis [15].

The Object Process Methodology (OPM), was invented and developed by Dov Dori, Visiting Professor, Department of Aeronautics and Astronautics, School of Engineering, Massachusetts Institute of Technology, Cambridge, MA, USA [16].

Professor Dori found in Occam razor, expression dating back to 14th century due to a logician priest, an important guide principle of the rising OPM:

"Entities should not be multiplied unnecessarily" [17].

As Professor Dov Dori tells, the human brain is trained to capture and analyse images earlier than the development of written language. Therefore, the idea is to move from the current use of textual descriptions into a modality where "text of course exists because it is the natural means of communication, but the text is grounded on some formal yet intuitive visual formalism" [18]. The goal would be to use a minimal set of concepts in order to move towards the "digital twin" of the complex system.

OPM is based on the Object-Process Theorem which asserts that "objects with states, processes and their relations among them constitute a necessary and sufficient universal ontology to describe a system". The aspects of the system that must be described are:

- Structure, the "static aspect", to say what the system consists of;
- Behaviour, the "dynamic aspect", to say "how the system changes over time";
- Function, to say "why the system is built, for whom the system is built and who benefits from operating the system" [19].

As it emerges from the above-mentioned theorem, OPM ontology is composed of three types of entities: objects, processes and states. Objects exist in a certain state (if they have states) and at a certain time in the system. Its graphical representation is a square. Processes transform objects: they generate objects, consume them or change their state; in other words, a process is what happens to an object and changes it. The graphical representation of a process is an ellipse.

These entities can be systemic, if they are part of the system, or environmental, if they are part of the system environment. In the first case, the line of the square or of the ellipse is continuum; in the latter one, the contour line is dotted.

The links which relate these entities are structural or procedural. The first one connects objects to each other or processes to each other and specifies a static aspect of the system. Structural links, in turn, can express relations, aggregation, exhibition, specialization and instantiation. Relational links have been used in the analysis when the relation in question could not be expressed with the other structural links because of its specific and particular nature. Aggregation-participation links were used to describe the parts by which the system consists of. Moreover, an object can be characterized, or it can exhibit another object and so the exhibition-characterization link. The difference between the two links can be explained by an example: a bag may contain highlighters (aggregation), but it always has shown a colour (exhibition). If a general object needed to be detailed by another object of the same class, but with more detailed characteristics, the generalization-specialization link was used.

If the need was to identify an object as the incarnation of a more general class of objects, the classification-instantiation link was used.

Procedural links are possible relations only between an object (or one of its state) and a process and they specify a dynamic aspect of the system. They may be of three types:

- Enable links which means that an object enables a process but is not affected by it. Link is different depending on what kind of enabler we want to specify: it can be human or non-human.
- Transforming links are used to explain the direct connections between on object and a process. In particular, they can indicate: consumption, if the linked object is consumed and eliminated by the process; result if the object is produced by the process; effect, if the linked object is affected by the process in general.
  Here can be highlighted a criticality of the method which will be resumed and detailed later.
- Invocation links are used to identify two consecutive processes in which the result of a process is not relevant in relation to the system and so it can be ignored.

Moreover, OPM provides two ways to refine the description of the system:

- Unfolding creates a new diagram with the unfolded object at the top. It can be refined by adding its attributes or parts. The parts ca be, in turn, unfolded and specified.
- In-zooming creates a new diagram with the in-zoomed process placed in the centre and enlarged, ready too be specified with the subprocesses that compose it. Inner processes can be, in turn, in-zoomed. The way the subprocesses are organized into the outer process, gives the dimension of time: proceeding from the top to the bottom ellipses, we can identify respectively the first, the subsequent and the final subprocess.

During the analysis it has been observed that all these features are well supported by the tool OPCAT which not only provides the set of OPM figures and links, but also displays a message of error when the user tries to do something that OPM does not allow.

The OPM model creates a unified view of the structural, functional and behavioural aspects of the system using bimodally graphics and texts. Object-Process Diagrams (OPDs) are the expression of the graphic modality and Object-Process Language (OPL) is the expression of the textual one. OPDs represent the entities of the model (objects, processes, states) and links and relations among them.

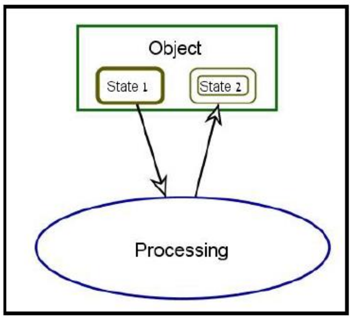


Figure 8: easy OPD example [20].

OPL describes the same OPM model in a subset of the chosen natural language. OPM shows four structural relations which involves objects and processes: generalization, aggregation, instantiation and exhibition. OPM ontology is also composed of procedural links between processes, such as effect, consumption, agent, instrument, result links, as well as time exception links between processes and invocation. Hierarchically organized OPDs compose an OPM model. The System Diagram (SD) represents the most abstract view of the system in which the system is described as a black box that performs a specific function, transforms some objects or use others as inputs. Each OPD, except for the SD, derives from a higher level OPD by refinement, zooming or unfolding. This mechanism of abstraction-refinement ensures that, proceeding towards lower levels, the overview of the whole is never lost. Each detail specified in a particular OPD is true for the system even if it appears only in that diagram. Moreover, if some detailed thing appears in an OPD, it is not necessary to specify all its details in another diagram which even contains that thing.

OPM holds twelve fundamental principles [19]:

1. The function as a Seed: the top level of a system is its main function
2. The model fact representation: this expression recalls what already specified, that is an OPM model fact needs to appear in at least one OPD in order for it to be represented in the model.
3. The timeline: the timeline within an in-zoomed process is directed by default from the top of the in-zoomed process ellipse to its bottom.
4. The Minimal Conceptual Modelling Language: a minimal ontology with fewer diagrams kinds and fewer symbols and relations among them, is more usable.
5. The Thing importance: there is a direct link between a thing and the higher level where that thing appears.
6. The Object transformation by Process: each process must be connected to at least one object or one state that the process transforms.

7. The Procedural Link Uniqueness: at any level of detail, an object and a process can relate to at most one procedural link, which uniquely determines the role of the object with respect to the process.
8. The Singular name: OPM allow only singulars. Plurals must be converted to singular by adding the word "set" for inanimate things and "Group" for humans.
9. The Graphic-Text Equivalence: each model fact expressed graphically in an OPD has its textual equivalent in an OPL paragraph.
10. The Thing Name Uniqueness: different things in an OPM Model which are not features, must have different names. Features are distinguishable by appending to them the reserves word "of" and the name of their exhibitor.
11. The Detail Hierarchy: whenever an OPD becomes difficult to be comprehended due to an excessive amount of details, a new descendent OPD shall be created.
12. The Skip Semantics Precedence: skip semantics takes precedence over wait semantics.

3.2 SySML VERSUS OPM

In order to find out if the MBSE approach to our PLATiNO programme can be advantageous over the traditional Document-Based approach, we must properly choose which modelling language best suits our analysis. Therefore, it is helpful to list similarities and differences between SySML and OPM presented previously.

An important feature of OPM is that it does not have different views or types of diagrams for a system but, rather, a single integrated model. SySML provides a lot of diagrams to represent the information that can be expressed with a single diagram in OPM, using objects, processes and relationships. Both languages support hierarchical representation of the model, but the way they do it is different: in SySML the model is represented in separate views with partial support of hierarchy; while in OPM the entire system model is built in one well-defined hierarchy. OPM is clearer and allows a better communicability. SySML diagrams are too detailed, making it difficult to grasp the general concepts of the system design. Moreover, OPM seems to be more navigable than a SySML model.

The main features of both languages are highlighted by the following Table:

Feature	SysML	OPM
Theoretical foundation	UML; Object-Oriented paradigm	Minimal universal ontology; Object-Process Theorem
Standard documentation number of pages	1670 (700 + 700 + 270)	130 (100 + 30)
Standardization body	OMG (2006)	ISO (2014)
Number of diagram kinds	9	1
Graphic modality	yes	yes
Textual modality	no	yes
Physical-informatical distinction	no	yes
Systemic-environmental distinction	no	yes

Figure 9: Main features of SySML and OPM [10].

As can be deduced from Figure 9, another difference between the two modelling language is in the textual modality which is absent in SySML (which is defined as a "graphical language"), instead OPM employs both, graphical ad textual modality. Next Table summarizes the characteristics of each modality:

Textual Representation	Graphical Representation
Expression of many details in a relatively small space	An easy way to get a general view of the system
Depicting constrains that are hardly expressible in the graphical representation	Easy to depict different relations among system components
Very flexible and can also include some formalism (mathematics, etc.)	The representation is usually more structured and formal
Must be read in a predefined order	Can be interpreted in a "random access" mode

Figure 10: Textual VS graphical modality [14].

We can gather that the choice of the suitable representation depends on both the desired level of details and the target audience. Really, technical people may need more detailed system description, so they should be provided with more written information; but also, non-technical people, who can always read text, often find it difficult to comprehend diagrams. Moreover, sometimes graphical representations tend to be ambiguous. Therefore, although to represent the whole system diagrams are easily human interpretable, some textual information is required to avoid potential misinterpretations.

In conclusion, we can state that both SysML and OPM provide a satisfying and expressive description of the system and they contain several same features [14].

However, we chose OPM modelling language to evaluate MBSE application to PLATiNO program for several reasons:

- It is innovative: SysML was adopted as a standard about eight years before OPM. Therefore, the latter is younger and its potentiality is still little known.
- It is more usable: textual parts might prevent misunderstandings among both stakeholders and team engineers.
- It is direct: lower levels of decomposition are manageable without loosing the global view of the system.
- It is easy: OPM has 130 standard pages against the 1670 of SysML. Therefore, the “know how” of OPM is of smaller entity, allowing a quick assimilation and an easy use of it.

- Its use is manageable within the period of a Master Thesis.
- There are very few examples of OPM applications to space systems; SySML is the most used language in space sector, even because it is older than OPM.
- It is minimal: for the Occam razor principle, “If you have two equally likely solutions to a problem, choose the simplest”.

3.3 The tool: OPCAT

OPCAT is an advanced, commercially available software platform which supports the OPM-based conceptual modelling of complex systems. It came to life in 2000 as a students’ project at the Technion; then it evolves arousing the interest of industrial and scientific domains, from banking through molecular biology to space engineering. This tool supports each phase of OPM system development including system requirements management and traceability and life cycle management. Moreover, it allows animated simulations of the model and automatic document generation [21].

OPCAT responds to an OPD construct, which is the user input, with an automatically generation of an OPL which shows the same OPD information. As we have previously reported to the attention, modelling with the exclusive use of diagrams may not be functional for complex systems because of the amount of details that diagrams should show. It would result in a difficult understanding by people involved in the project, technical and non-technical. For this reason, OPM provides OPL paragraphs corresponding to simple OPD diagrams showing essential information. In this sense, OPCAT implements three abstraction/refinement mechanisms:

1. Unfolding/Folding: it is applied to objects and “is used for refining/abstracting the structural hierarchy of a thing”.
2. In-zooming/Out-zooming: it is applied to processes and “exposes/hides the inner details of a thing within its frame”.
3. Expressing/Suppressing: it is applied to states, it reveals/hides the objects’ states [21].

The first step to model a complex system in OPCAT is that of building the primary OPD that is the System Diagram. It holds all the main function of the system which represents the central process. Then, it must be specified the essence of the process and its origin: the essence may be physical or informatical and the origin may be systemic or environmental. Environmental things do not belong to the system, so their design is independent, but interact with it. Next Table provides an overview of the entities which appear in an OPM and OPCAT environment.

Symbol		Name: Definition	OPL	Semantics/ Effect on the system flow/ Comments
Things	A	Object A: A thing that exists	A is physical [and environmental].	A is informational and systemic by default.
	B	Process B: A thing that transforms (generates, consumes, or changes the state of an) object.	B is physical [and environmental].	B is informational and systemic by default.
A s1 s2		State: A situation of an object.	A is s1. A can be s1 or s2. A can be s1, s2, or s3.	Always within an object.

Figure 11: OPM and OPCAT entities [21].

Progressively, the other parts of the system are inserted as refinements (specification of parts) of the Things in the SD.

Next chapter provides the example of application of this tool to our case study.

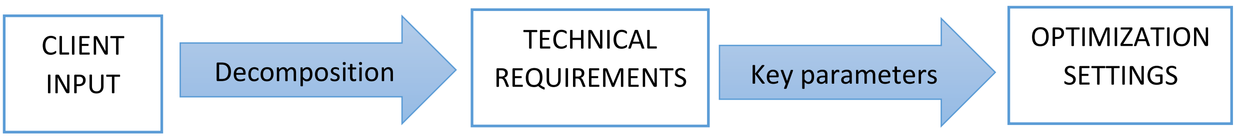
4. CASE STUDY

4.1 PLATiNO PROGRAMME

PLATiNO programme lent itself to this type of analysis because it is an example of modern complex system. In fact, it foresees an innovative high-tech space small satellite platform (<200kg) , all-electric and multi-purpose. It is financed by ASI and the Italian Government and defines the achievement of the in-flight qualification with two missions scheduled in 2022 and 2023. The project involves several companies in addition to SITAEL, such as Leonardo, Thales Alenia Space Italia and Airbus [22] [23] [24].

PLATiNO platform is multi-applicability, so it foresees the possibility to be re-used for the accommodation of several payloads without be re-designed. In particular, PLATiNO 1 mission will be an Earth Observation X-Band SAR mission.

The use of OPM trough the related OPCAT digital tool, applied to PLATiNO, significantly can improve its management. In fact, because of the complexity of the problem in terms of technical realization, but also of companies and people involved, experimenting this road seemed a good occasion of research and potential evolution for SITAEL. In particular, the carried-out analysis aims to give its contribute to the first steps of the so called "optimization environment", as displayed by the following scheme, which renders the optimization workflow.



I proceeded taking into account that the analysis should highlight what should be valid for every PLATiNO mission and what was subject to change depending on the purpose of the mission.

The focus point was PLATiNO 1 mission. I attempted to describe its characteristics in terms of phases of mission, scenarios, platform features, states of the satellite and modes of subsystems, configurations of the satellite. In particular, the new diagrams realized with OPM could substitute the pages of the description of the characteristics of the mission orbits and of the features of the subsystems, or the tables of the mass budget or of the power budget.

4.2 MAIN EXISTING PROBLEMS

Several issues already raised up during the first stages of PLATiNO design which drove the need to probe the OPM direction. They can be divided into two main categories: communication and design description. The first one concerns the difficulty of conveying information among the team members and among the companies involved; the latter concerns the difficulty of acquiring all the starting requirements which will be the design drivers.

The following table better summarize these concepts:

	PAINS	GAINS
COMMUNICATION	➢ DATA STORED IN SEVERAL DOCUMENTS WITH DIFFERENT SUPPORTS ➢ LOSS OF INFORMATION ➢ REDUCED TIME TO MARKET ➢ «EXCEL ENGINEERING»	➢ STANDARD LANGUAGE ➢ UNAMBIGUOUS LANGUAGE ➢ REDUCED DOCUMENTATION
TECHNICAL DESIGN	➢ ESTABLISHING A SOLID REQUIREMENT BASELINE ➢ PERFORMING DESIGN TRADE OFF AND DRIVIGN DESIGN CHOICES ➢ CUSTOMER REQUIREMENTS ANALYSIS	➢ IMPROVEMENT OF DESIGN QUALITY ➢ INCREASE SE ACTIVITIES EFFICIENCY ➢ EASY TO USE APPROACH

Figure 12: potential benefits of OPM approach.

PLATiNO Programme requires the synergic effort of Airbus, Thales Alenia Space, Leonardo and Sitael. Each of these companies makes its part in the realization of the project which is characterized by a huge quantity of data and a reduced time to market. These data are stored in several documents realized with different supports (such as word, excel, pdf…). In particular, it is spoken of Systems engineering as "Excel Engineering" wanting to express the proliferation of excel files containing mass budget, power budget and so on. Each worksheet exists in a lot of updated versions because of the iterative nature of space projects, so it is easy to imagine the propensity to mistakes of this way to proceed. Sometimes some information gets lost and it needs time to find out the mistake, correct it and go on.

In terms of technical design, so far and still now initial requirements deriving from customer are inserted in a textual form into DOORS. On this platform, the decomposition of the system appears in the form of bulleted list, so it is not easy to clearly re-join in mind the last levels requirements to the first ones. This method turns to be fragmented, complex and dispersive and DOORS license has a cost. Moreover, in this way it is difficult to individuate some trade off which should be done in order to improve and optimize the architecture.

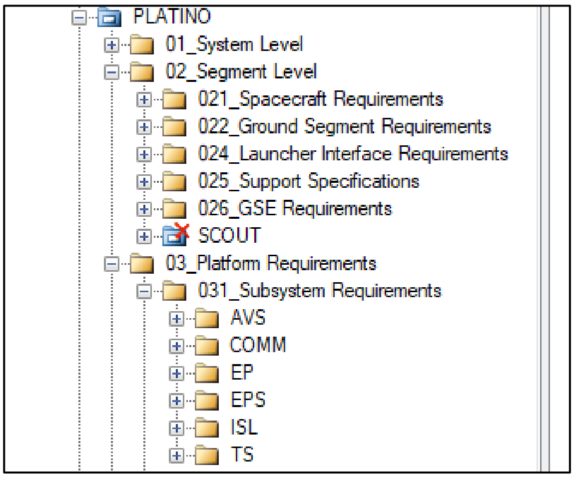


Figure 13: the numerous DOORS textual folders.

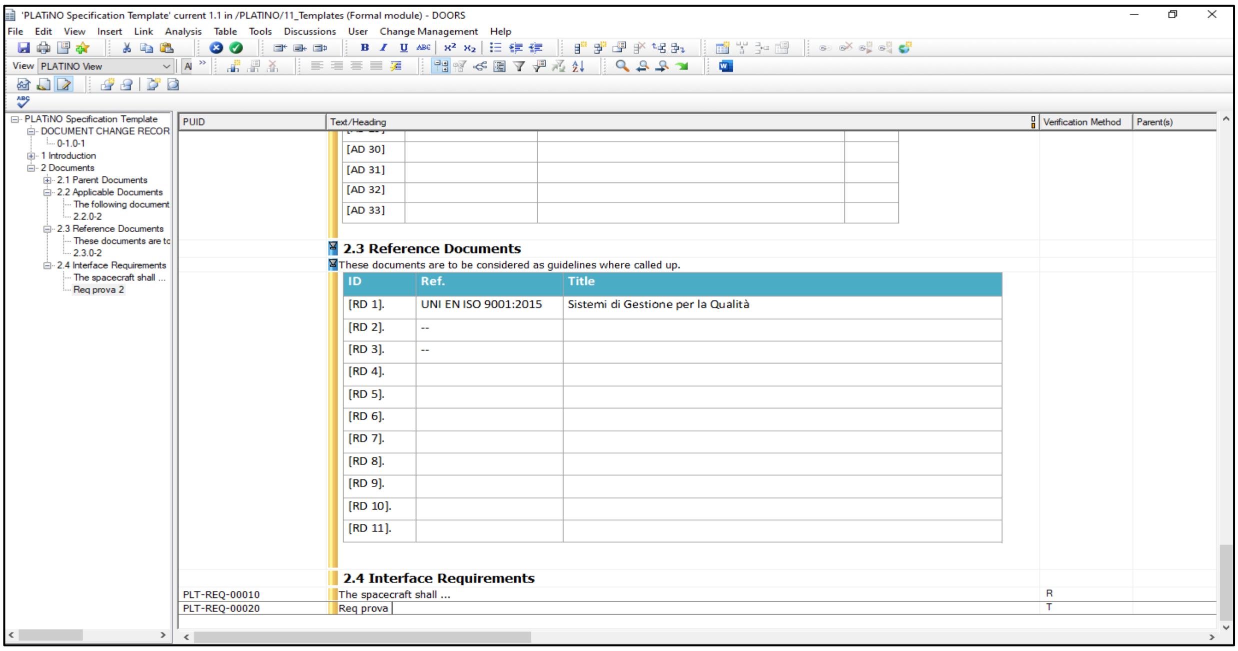


Figure 14: Example of DOORS application.

4.3 DEVELOPMENT OF THE OPM ANALYSIS

It is important to highlight that in the following diagrams, numerical inserted values are not the actual numerical project data because of the need to protect corporate privacy.

4.3.1 OPDs HIERARCHY

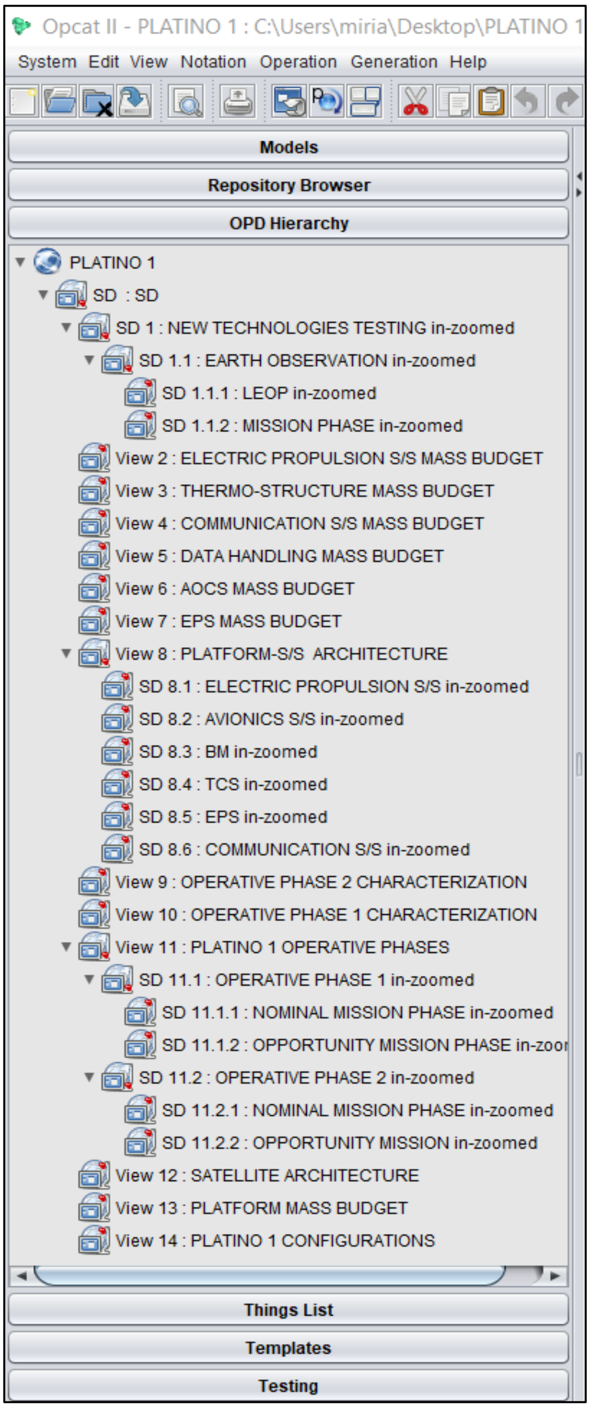


Diagram 1: OPCAT diagrams hierarchy.

Even the list of the development of the system in OPCAT provides the idea of the multi-level decomposition. This screen gives the overall vision of the several system aspects taken into consideration.

4.3.2 PLATiNO Programme physical architecture

The following system diagram is the top-level OPD and represents the main aim of PLATiNO programme (represented as OPM "function"). It is used to locate the system progressively analysed, PLATiNO 1 satellite, into the context of PLATiNO programme.

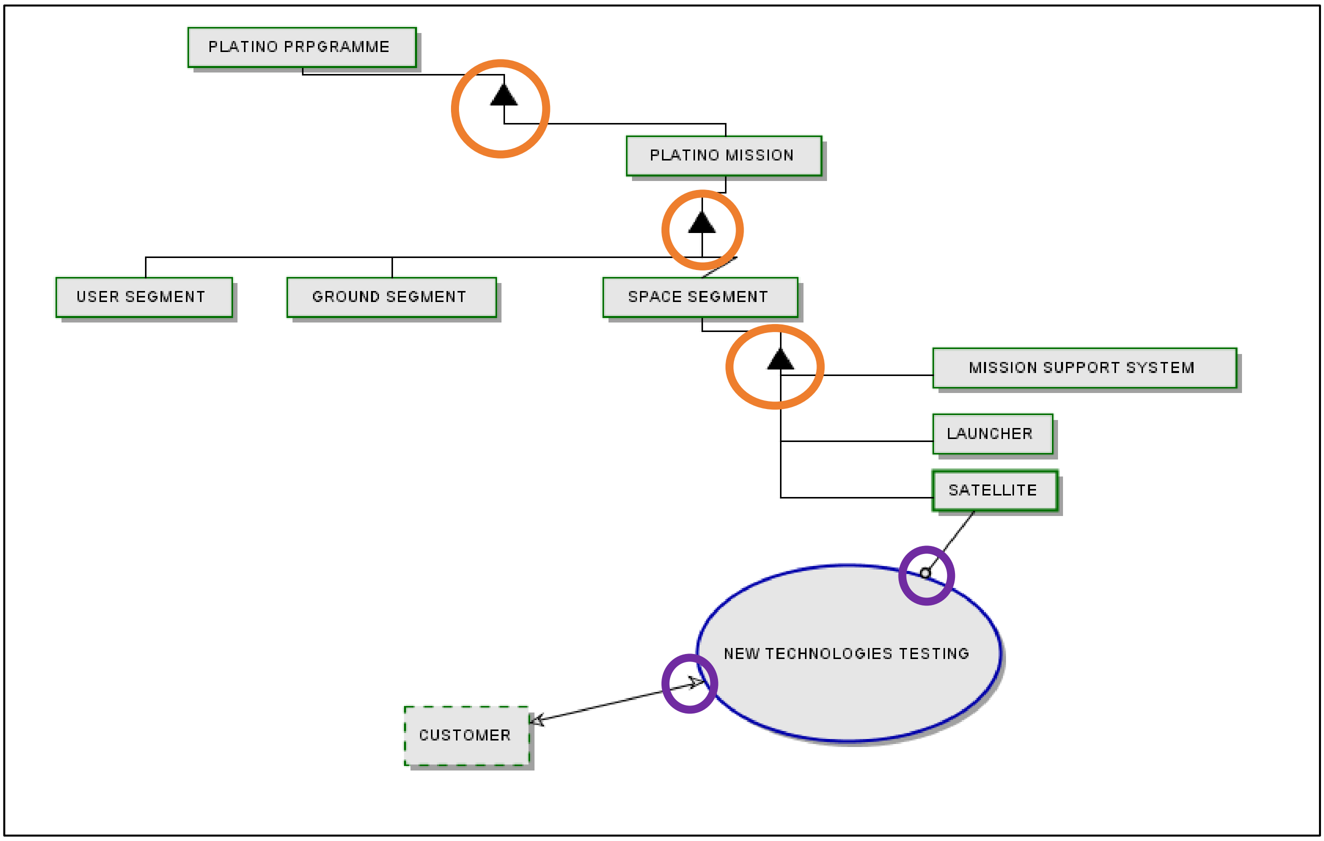


Diagram 2: System Diagram (OPD).

The equivalent textual part automatically generated is:

CUSTOMER is environmental and physical.
PLATINO PRPGRAMME is physical.
PLATINO PRPGRAMME consists of PLATINO MISSION.
PLATINO MISSION is physical.
PLATINO MISSION consists of USER SEGMENT, SPACE SEGMENT, and GROUND SEGMENT.
USER SEGMENT is physical.
SPACE SEGMENT is physical.
SPACE SEGMENT consists of LAUNCHER, SATELLITE, and MISSION SUPPORT SYSTEM.
LAUNCHER is physical.
SATELLITE is physical.
MISSION SUPPORT SYSTEM is physical.
GROUND SEGMENT is physical.
NEW TECHNOLOGIES TESTING is physical.
NEW TECHNOLOGIES TESTING requires SATELLITE.
NEW TECHNOLOGIES TESTING affects CUSTOMER.

Diagram 3: System Diagram (OPL).

In this starting diagram and on its related textual part, one type of structural link (highlighted in orange) and two types of procedural link (highlighted in violet) can be observed. The structural link appears three times and it is an aggregation/participation one. It means that, for example, PLATiNO 1 mission is a part of PLATiNO programme; PLATiNO programme is the high level thing, whereas PLATiNO 1 mission is the lower level one.

The first procedural link which relates the object “satellite” and the process “new technologies testing” is an “enabling link”. It means that the satellite allows the process of testing new technologies. The circle on the ellipse boundary is white because the enabler is non-human; if the enabler was a human or a group of humans, that circle would be black. The corresponding OPL is “new technologies testing requires satellite”.

The second procedural link is an effect link and the corresponding OPL is “new technologies testing affects costumer” because the test of new technologies concerns the costumer needs.

It can be highlighted that this type of link does not specify “how the process affects the object”.

4.3.3 PLATiNO 1 functional architecture

Making an in-zoom into the process “new technologies testing”, it can be obtained another level of the system which specifies how this process can be realized.

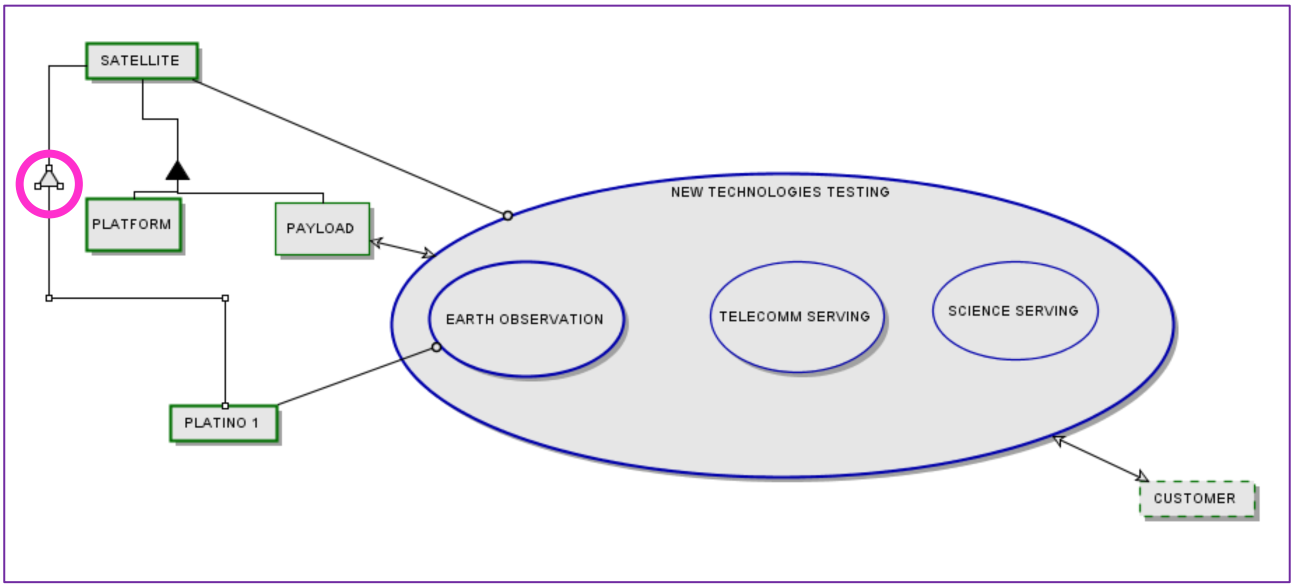


Diagram 4: New technologies testing in-zoomed (OPD).

The equivalent OPL is:

CUSTOMER is environmental and physical.
SATELLITE is physical.
SATELLITE consists of PAYLOAD and PLATFORM.
  PAYLOAD is physical.
  PLATFORM is physical.
PLATINO 1 is physical.
PLATINO 1 is a SATELLITE.
NEW TECHNOLOGIES TESTING is physical.
NEW TECHNOLOGIES TESTING consists of EARTH OBSERVATION, TELECOMM SERVING, and SCIENCE SERVING.
NEW TECHNOLOGIES TESTING requires SATELLITE.
NEW TECHNOLOGIES TESTING affects PAYLOAD and CUSTOMER.
NEW TECHNOLOGIES TESTING zooms into SCIENCE SERVING, TELECOMM SERVING, and EARTH OBSERVATION.
  TELECOMM SERVING is physical.
  EARTH OBSERVATION is physical.
  EARTH OBSERVATION requires PLATINO 1.

Diagram 5: New technologies testing in-zoomed (OPL).

The new structural link (pink circle) which can be noted is a generalization/specialization one. Therefore, the meaning is that the general satellite specializes itself in PLATiNO 1.

PLATiNO 1 satellite must perform a mission whose scope is the Earth Observation. In order to show what are the mission phases which allow the achievement of the purpose, the following diagram is useful:

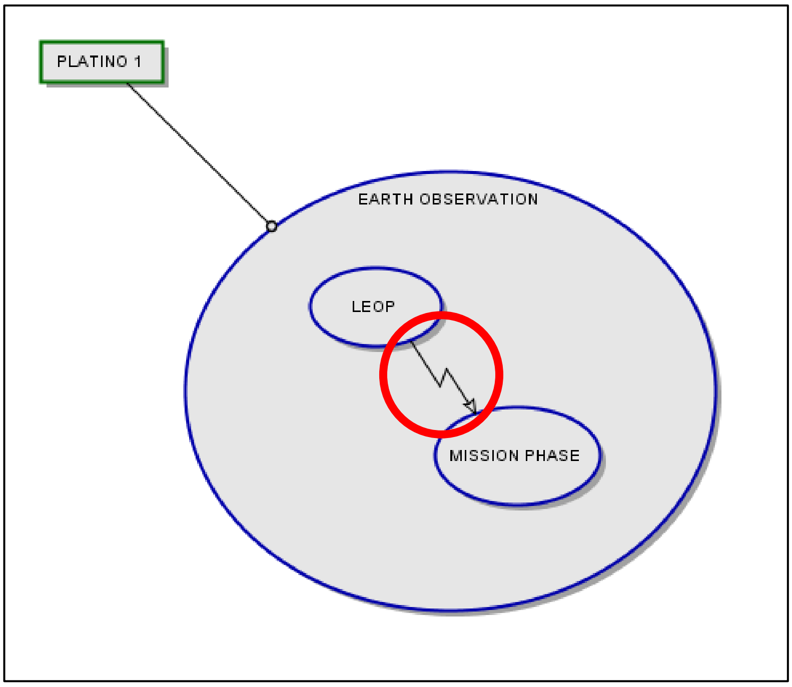


Diagram 6: Earth observation in-zoomed (OPD).

It is an in-zoom diagram descending from the high level process "Earth Observation", which explains the mission phases which allow PLATiNO 1 satellite to perform the mission. In its simplicity, it is clear and provides fundamental information, as the related OPL demonstrate.

PLATINO 1 is physical.
EARTH OBSERVATION is physical.
EARTH OBSERVATION consists of LEOP and MISSION PHASE.
EARTH OBSERVATION requires PLATINO 1.
EARTH OBSERVATION zooms into LEOP and MISSION PHASE.
 LEOP is physical.
 LEOP invokes MISSION PHASE.
 MISSION PHASE is physical.

Diagram 7: Earth observation in-zoomed (OPL).

It can be observed a new procedural link (red circle) which explains the sequence in which the two processes perform and the fact that only when the first one ends, the latter occurs. It is called "invocation link" and provides the way to ignore the irrelevant object product of the first object, allowing to consider the really "product" of the first process which is the possibility to perform the subsequent mission phase. This link even highlights the fact that the "mission phase" cannot start before the "LEOP" is completed. The execution order of the processes is even shown by their position in the big ellipse: the flow of information moves from top to bottom, so that the invocation link has a strengthening function.

4.3.4 PLATiNO 1 mission phases-satellite states-AOCS modes matching

Next diagram shows the LEOP scenarios and the relations between them and the states of the satellite and the modes of AOCS subsystem.

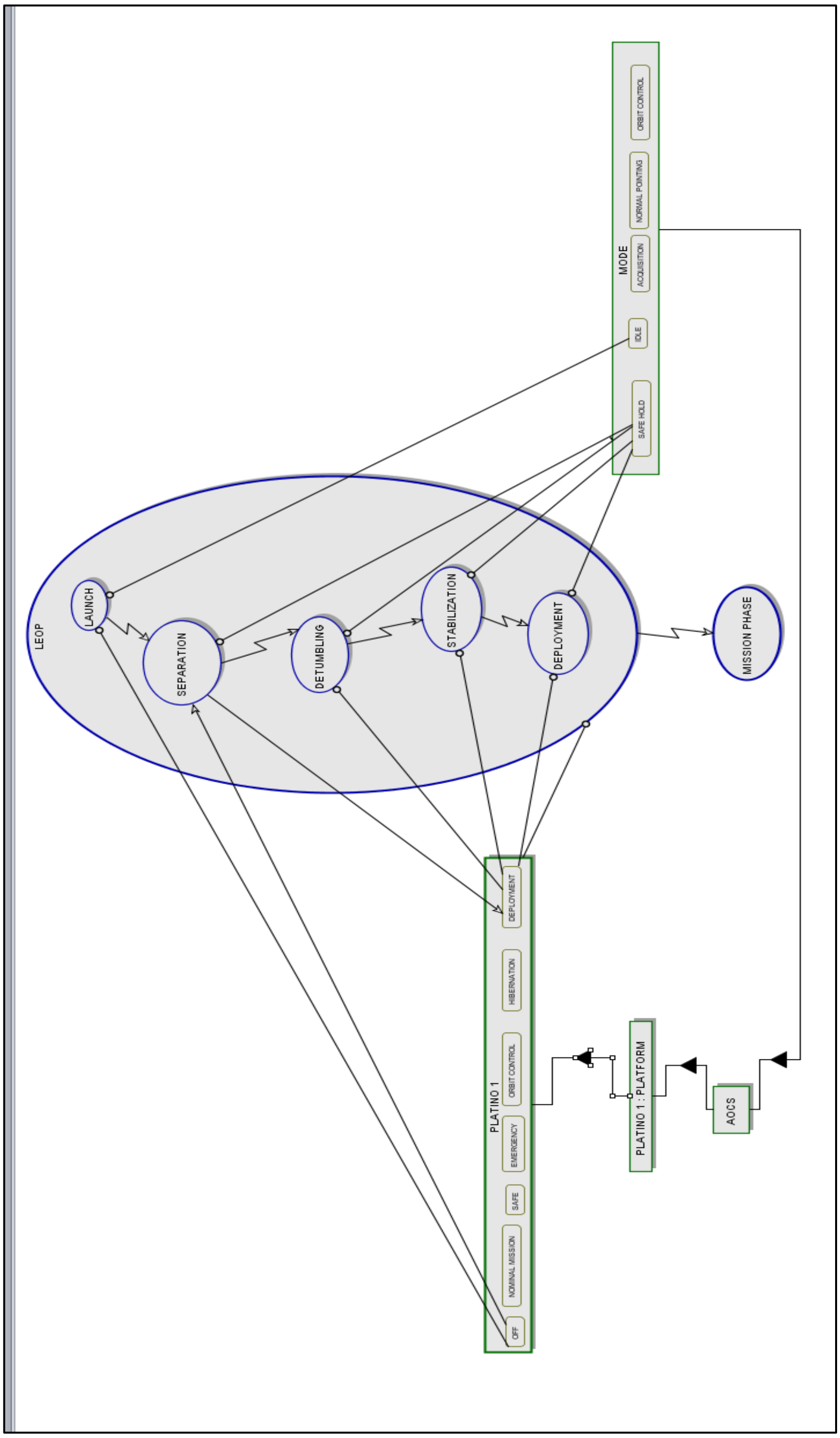


Diagram 8: LEOP in-zoomed (OPD).

The equivalent OPL is:

PLATINO 1 is physical.
PLATINO 1 can be OFF, DEPLOYMENT, SAFE, EMERGENCY, NOMINAL MISSION, ORBIT CONTROL, or HIBERNATION.
PLATINO 1 consists of PLATINO 1 : PLATFORM.
PLATINO 1 : PLATFORM is physical.
PLATINO 1 : PLATFORM consists of AOCS.
AOCS is physical.
AOCS consists of MODE.
MODE can be IDLE, SAFE HOLD, ACQUISITION, NORMAL POINTING, or ORBIT CONTROL.
MISSION PHASE is physical.
LEOP is physical.
LEOP consists of LAUNCH, SEPARATION, DETUMBLING, STABILIZATION, and DEPLOYMENT.
LEOP requires PLATINO 1.
LEOP invokes MISSION PHASE.
LEOP zooms into LAUNCH, SEPARATION, DETUMBLING, STABILIZATION, and DEPLOYMENT.
LAUNCH is physical.
LAUNCH requires IDLE MODE and OFF PLATINO 1.
LAUNCH invokes SEPARATION.
SEPARATION is physical.
SEPARATION requires SAFE HOLD MODE.
SEPARATION changes PLATINO 1 from OFF to DEPLOYMENT.
SEPARATION invokes DETUMBLING.
DETUMBLING is physical.
DETUMBLING requires SAFE HOLD MODE and DEPLOYMENT PLATINO 1.
DETUMBLING invokes STABILIZATION.
STABILIZATION is physical.
STABILIZATION requires SAFE HOLD MODE and DEPLOYMENT PLATINO 1.
STABILIZATION invokes DEPLOYMENT.
DEPLOYMENT is physical.
DEPLOYMENT requires SAFE HOLD MODE and DEPLOYMENT PLATINO 1.

Diagram 9: LEOP in-zoomed (OPL).

Even the MISSION PHASE consists of several scenarios, so the same scenarios-satellite states-AOCS modes is shown.

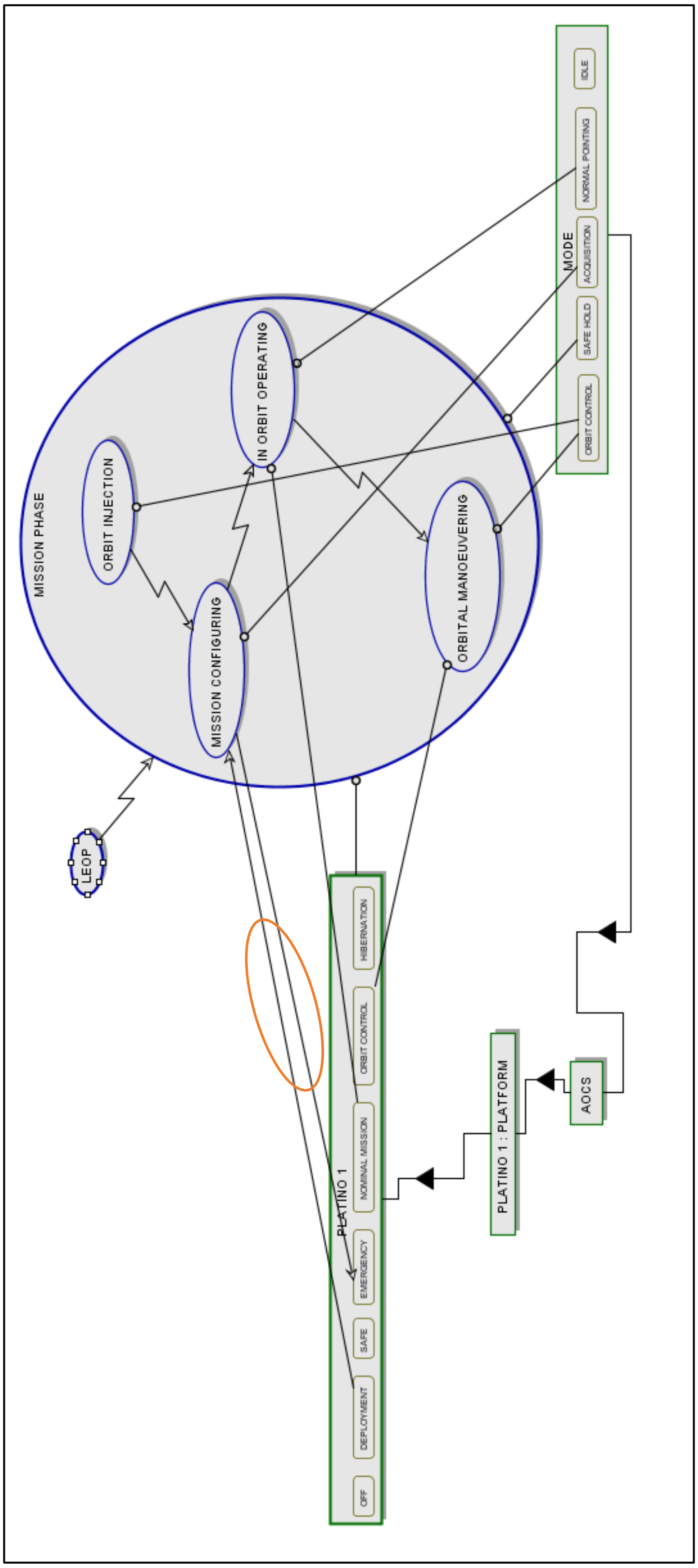


Diagram 10: Mission phase in-zoomed (OPD).

It is important to note as the process of “mission configuring” changes the state of PLATiNO 1 from “deployment” to “normal mission” (orange circle). The corresponding OPL sentence is squared in orange.

PLATINO 1 is physical.
PLATINO 1 can be OFF, DEPLOYMENT, SAFE, EMERGENCY, NOMINAL MISSION, ORBIT CONTROL, or HIBERNATION.
PLATINO 1 consists of PLATINO 1 : PLATFORM.
    PLATINO 1 : PLATFORM is physical.
    PLATINO 1 : PLATFORM consists of AOCS.
        AOCS is physical.
        AOCS consists of MODE.
            MODE can be IDLE , SAFE HOLD, ACQUISITION, NORMAL POINTING, or ORBIT CONTROL.
LEOP is physical.
LEOP invokes MISSION PHASE.
MISSION PHASE is physical.
MISSION PHASE consists of MISSION CONFIGURING, IN ORBIT OPERATING, ORBITAL MANOEUVERING, and ORBIT INJECTION.
MISSION PHASE requires SAFE HOLD MODE and PLATINO 1.
MISSION PHASE zooms into ORBIT INJECTION, MISSION CONFIGURING, IN ORBIT OPERATING, and ORBITAL MANOEUVERING.
    ORBIT INJECTION is physical.
    ORBIT INJECTION requires ORBIT CONTROL MODE.
    ORBIT INJECTION invokes MISSION CONFIGURING.
    MISSION CONFIGURING is physical.
    MISSION CONFIGURING requires ACQUISITION MODE.
    MISSION CONFIGURING changes PLATINO 1 from DEPLOYMENT to EMERGENCY.
    MISSION CONFIGURING invokes IN ORBIT OPERATING.
    IN ORBIT OPERATING is physical.
    IN ORBIT OPERATING occurs if MODE is NORMAL POINTING.
    IN ORBIT OPERATING requires NOMINAL MISSION PLATINO 1.
    IN ORBIT OPERATING invokes ORBITAL MANOEUVERING.
    ORBITAL MANOEUVERING is physical.
    ORBITAL MANOEUVERING occurs if MODE is ORBIT CONTROL.
    ORBITAL MANOEUVERING requires ORBIT CONTROL PLATINO 1.

Diagram 11: Mission phase in-zoomed (OPL).

4.3.5 PLATiNO 1 satellite physical architecture

Next diagram provides a view of the PLATiNO 1 satellite architecture:

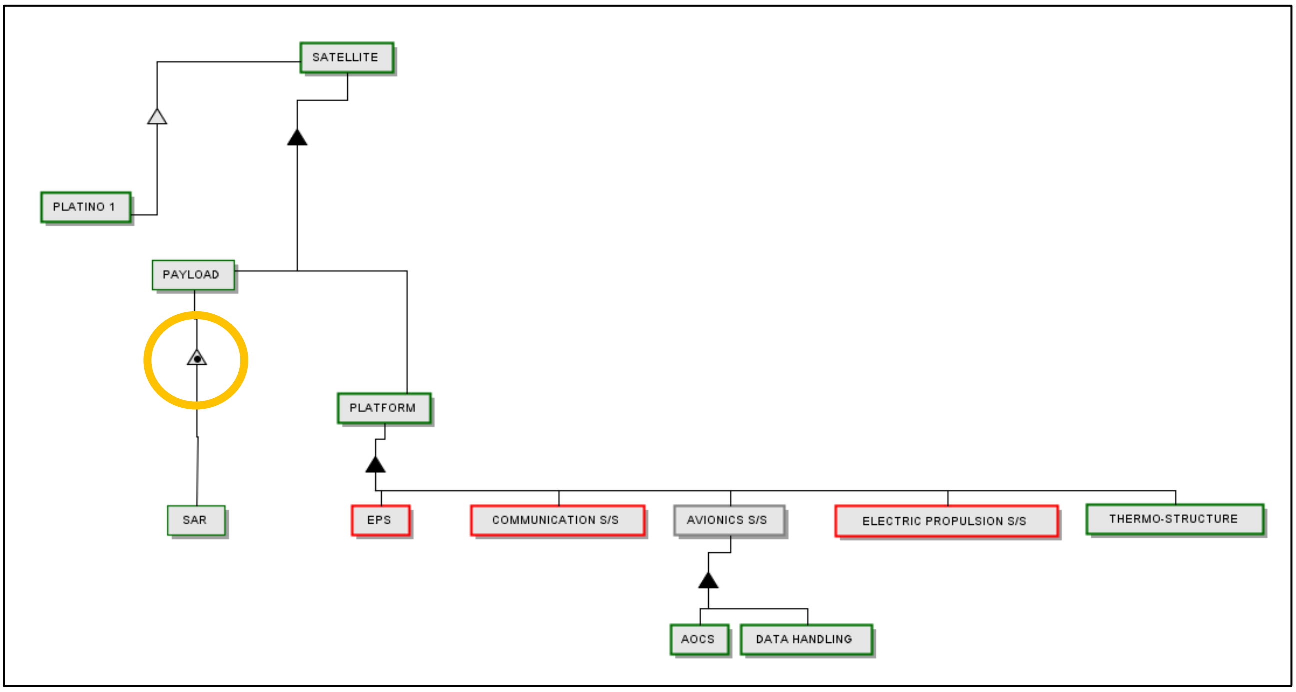


Diagram 12: Satellite architecture (OPD).

It has been obtained by unfold from the System Diagram. Some platform subsystems objects show a red square rather than a green: it means that they hide an in-zoom vision. It can be observed a new structural link (yellow circle) which means that the SAR is an example of the payload that PLATiNO satellite can accommodate, related to PLATiNO 1 mission; in fact, PLATiNO 2 satellite will accommodate another payload. Therefore, the equivalent OPL is:

SATELLITE is physical.
SATELLITE consists of PAYLOAD and PLATFORM.
PAYLOAD is physical.
PLATFORM is physical.
PLATFORM consists of THERMO-STRUCTURE, EPS, COMMUNICATION S/S, AVIONICS S/S, and ELECTRIC PROPULSION S/S.
THERMO-STRUCTURE is physical.
EPS is physical.
COMMUNICATION S/S is physical.
AVIONICS S/S is physical.
AVIONICS S/S consists of AOCS and DATA HANDLING.
AOCS is physical.
DATA HANDLING is physical.
ELECTRIC PROPULSION S/S is physical.
PLATINO 1 is physical.
PLATINO 1 is a SATELLITE.
SAR is physical.
SAR is instance of a PAYLOAD.

Diagram 13: Satellite architecture (OPL).

The following diagram shows a clear view of the possible physical configurations of PLATiNO 1 satellite:

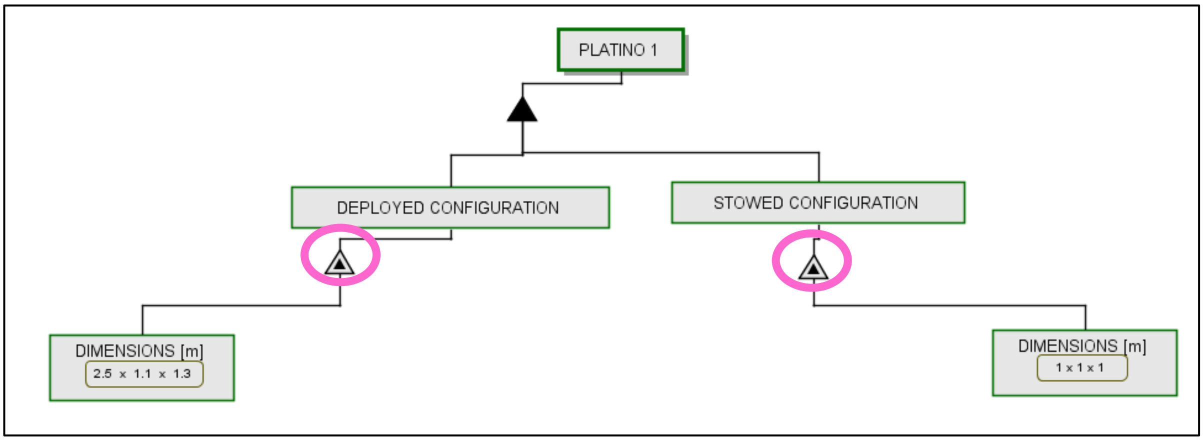


Diagram 14: PLATiNO 1 configurations (OPD).

Despite its apparent simplicity, it provides important global information about the dimensions of PLATiNO 1 satellite. In particular, a new structural link has been used (pink circle): it is the exhibition/characterization link which denotes that PLATiNO 1 configuration, which can be deployed or stowed, has an attribute expressible by a value (in this case, the dimensions). The corresponding OPL is:

PLATINO 1 is physical.
PLATINO 1 consists of DEPLOYED CONFIGURATION and STOWED CONFIGURATION.
DEPLOYED CONFIGURATION exhibits DIMENSIONS [m].
DIMENSIONS [m] is 2.5 x 1.1 x 1.3.
STOWED CONFIGURATION exhibits DIMENSIONS [m].
DIMENSIONS [m] is 1 x 1 x 1.

Diagram 15: PLATiNO 1 configurations (OPL).

PLATiNO 1 satellite is composed of a payload, its main feature, and a platform which should be reused for PLATiNO 2 mission and others. The physical architecture of PLATiNO platform is showed in the following diagram:

4.3.6 PLATiNO Platform physical architecture

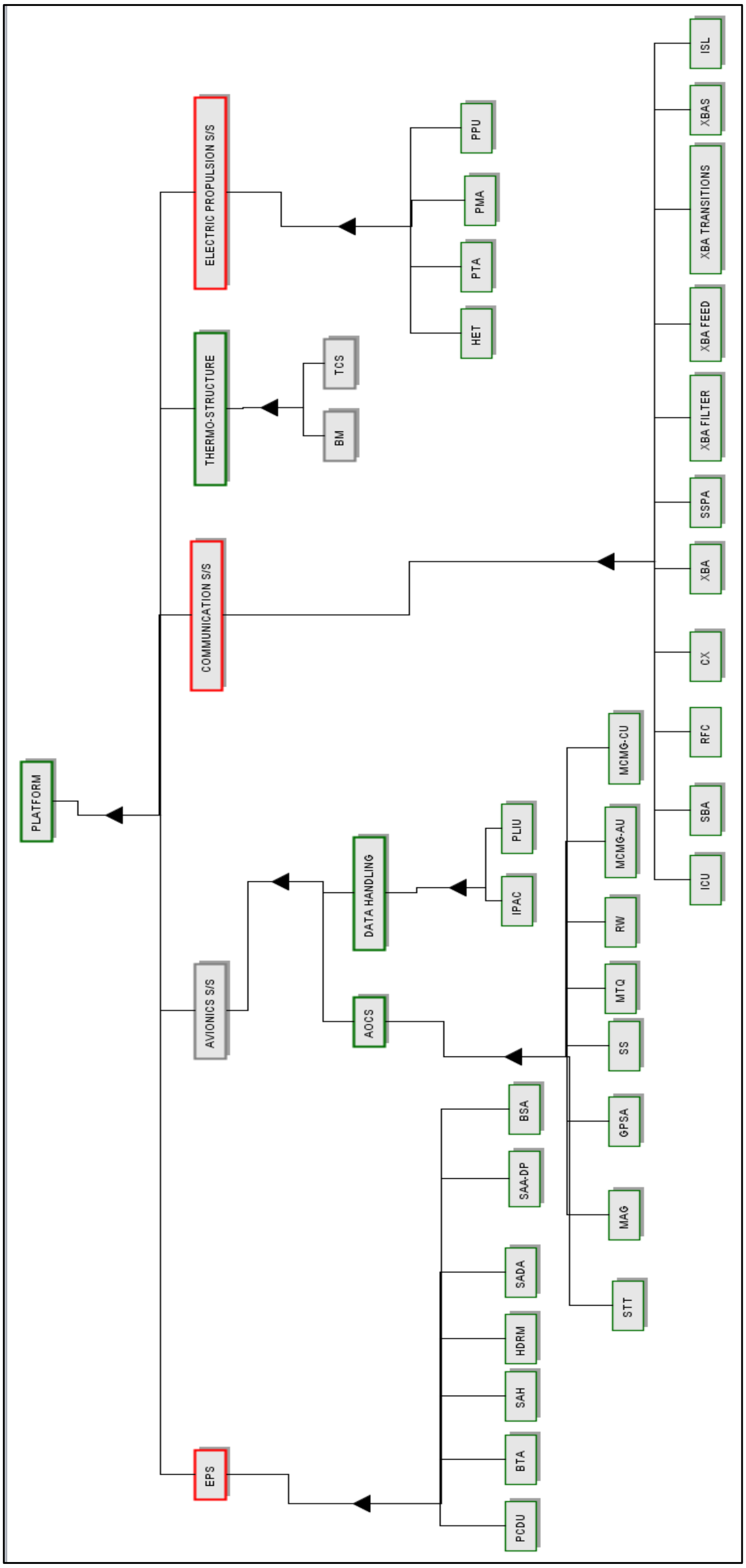


Diagram 16: Platform S/S architecture (OPD).

PLATiNO 1 platform specifies itself in its parts which are: the Electrical Power System (EPS), the Avionics subsystem (Avionics S/S), the Communication Subsystem, the Thermo-Structure subsystem, the Electrical Propulsion subsystem. The parts of the Avionics Subsystem are: the Data Handling subsystem and the Attitude and Orbit Control System (AOCS). Each subsystem, in turn, is made up of several parts. EPS is composed of the Power Control & Distribution Unit (PCDU), the Battery Assembly (BTA), the SA Hinge (SAH), the SA HDRM (HDRM), the Mini-Solar Array Drive Assembly (SADA), the Solar Array Assembly-Deployable (SAA-DP), the Solar Array Assembly-Body-Mounted (BSA). Data Handling consists of the Integrated Power Avionic Communication (IPAC) and the P/L Interface Custom Unit (PLIU). AOCS parts are: Star Tracker (STT), Magnetometer (MAG), Sun Sensors (SS), GPS Antenna (GPSA), Magneto-torquer (MTQ), Reaction Wheel (RW), Mini-Control Moment Gyro AU (MCMG-AU), Mini-Control Moment Gyro CU (MCMG-CU). Communication subsystem consists of: Integrated Communication Unit (ICU), the S-band Antenna (SBA), the RF components (RFC), the Coaxial Cables (CX), the Active X-band Antenna (XBA), the Solid State Power Amplifier (SSPA), the X-Band filter (XBA filter), the X-band feed (XBA Feed), the X-band transitions (XBA transitions), the X-band antenna switch (XBAS), the Inter-Satellite Link Unit (ISL). The thermo-structure foresees a Bus Module Structure (BM) and a Thermal Control (TCS). The Electric Propulsion Subsystem is composed of the Hall Effect Thruster (HET), the Propellant Tank Assembly (PTA), the Propellant Management Assembly (PMA), the Power Processing Unit (PPU).

These lines are efficiently summarized in the diagram above: if the mouse is hovered over the boxes, the entire name of the part appears.

The following equivalent OPL specifies even the fact that the parts of the platform are physical ones:

PLATFORM is physical.
PLATFORM consists of THERMO-STRUCTURE, EPS, COMMUNICATION S/S, AVIONICS S/S, and ELECTRIC PROPULSION S/S.
THERMO-STRUCTURE is physical.
THERMO-STRUCTURE consists of BM and TCS.
BM is physical.
TCS is physical.
EPS is physical.
EPS consists of PCDU, BTA, SAH, HDRM, SADA, SAA-DP, and BSA.
PCDU is physical.
BTA is physical.
SAH is physical.
HDRM is physical.
SADA is physical.
SAA-DP is physical.
BSA is physical.
COMMUNICATION S/S is physical.
COMMUNICATION S/S consists of ICU, SBA, RFC, CX, XBA, SSPA, XBA FILTER, XBA FEED, XBA TRANSITIONS, XBAS, and ISL.
ICU is physical.
SBA is physical.
CX is physical.
XBA is physical.
SSPA is physical.
XBA FILTER is physical.
XBA FEED is physical.
XBA TRANSITIONS is physical.
XBAS is physical.
ISL is physical.
AVIONICS S/S is physical.
AVIONICS S/S consists of AOCS and DATA HANDLING.
AOCS is physical.
AOCS consists of STT, MAG, SS, GPSA, MTQ, RW, MCMG-AU, and MCMG-CU.
STT is physical.
MAG is physical.
SS is physical.
GPSA is physical.
MTQ is physical.
RW is physical.
MCMG-AU is physical.
MCMG-CU is physical.
DATA HANDLING is physical.
DATA HANDLING consists of IPAC and PLIU.
IPAC is physical.
PLIU is physical.
ELECTRIC PROPULSION S/S is physical.
ELECTRIC PROPULSION S/S consists of HET, PTA, PMA, and PPU.
HET is physical.
PTA is physical.
PMA is physical.
PPU is physical.

Diagram 17: Platform S/S architecture (OPL).

From this view, several in-zoom visions can be obtained on order to specify the functional architecture of the subsystems. The first one is the electric propulsion subsystem.

4.3.7 Subsystems' functional architecture

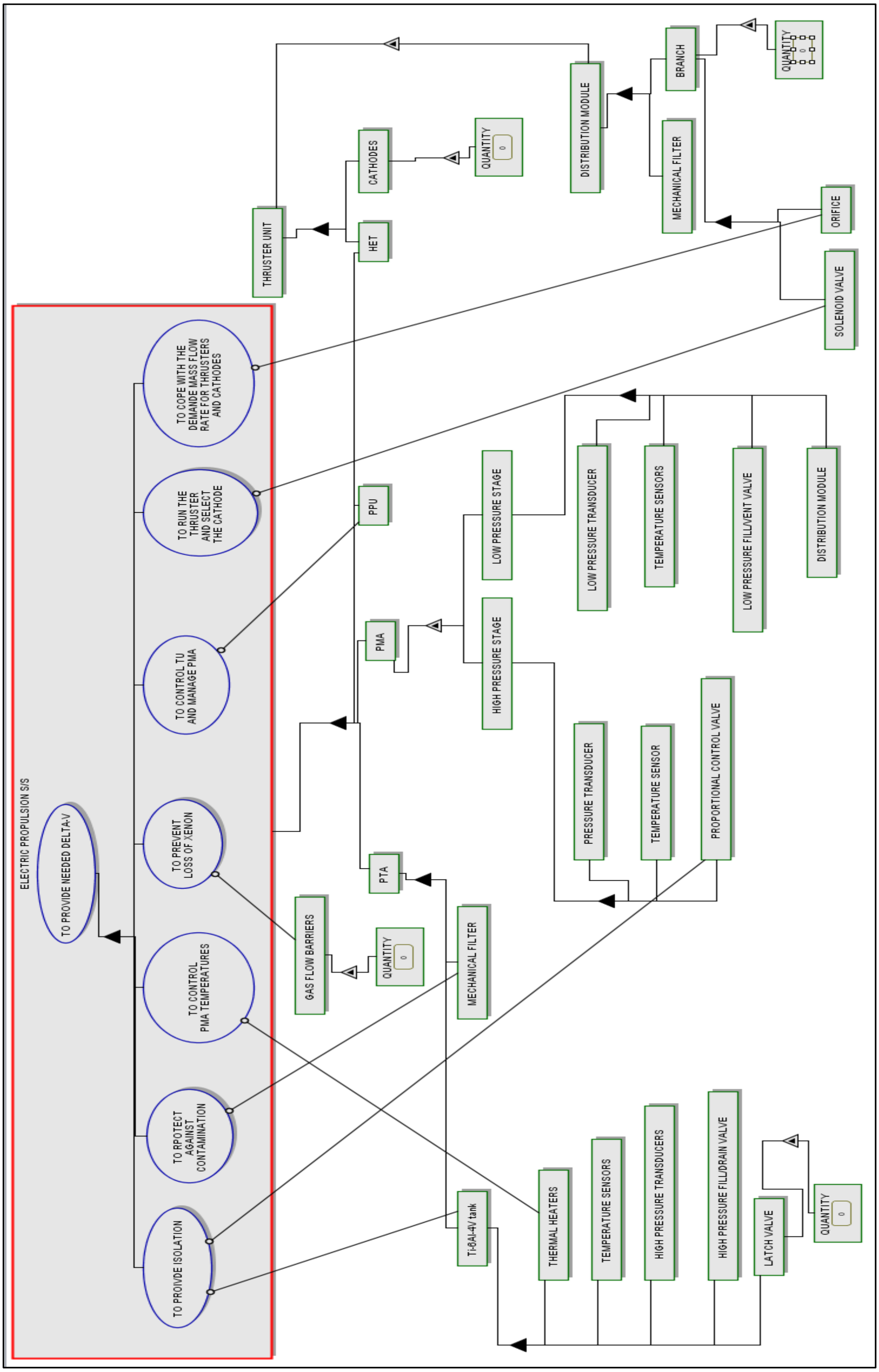


Diagram 18: Electric propulsion S/S in-zoomed (OPD).

THRUSTER UNIT is physical.
THRUSTER UNIT exhibits DISTRIBUTION MODULE.
DISTRIBUTION MODULE is physical.
DISTRIBUTION MODULE consists of MECHANICAL FILTER and BRANCH.
MECHANICAL FILTER is physical.
BRANCH is physical.
BRANCH exhibits QUANTITY.
QUANTITY is 0.
BRANCH consists of SOLENOID VALVE and ORIFICE.
SOLENOID VALVE is physical.
ORIFICE is physical.
THRUSTER UNIT consists of HET and CATHODES.
HET is physical.
CATHODES is physical.
CATHODES exhibits QUANTITY.
QUANTITY is 0.
GAS FLOW BARRIERS is physical.
GAS FLOW BARRIERS exhibits QUANTITY.
QUANTITY is 0.
ELECTRIC PROPULSION S/S is physical.
ELECTRIC PROPULSION S/S exhibits TO PROIVDE ISOLATION, TO RPOTECT AGAINST CONTAMINATION, TO COPE WITH THE DEMANDE MASS FLOW RATE FOR THRUSTERS AND CATHODES, TO CONTROL PMA TEMPERATURES, TO RUN THE THRUSTER AND SELECT THE CATHODE, TO PREVENT LOSS OF XENON, TO CONTROL TU AND MANAGE PMA, and TO PROVIDE NEEDED DELTA-V.
ELECTRIC PROPULSION S/S consists of HET, PTA, PMA, and PPU.
PTA is physical.
PTA consists of Ti-6Al-4V tank and MECHANICAL FILTER.
Ti-6Al-4V tank is physical.
Ti-6Al-4V tank consists of THERMAL HEATERS, TEMPERATURE SENSORS, HIGH PRESSURE TRANSDUCERS, HIGH PRESSURE FILL/DRAIN VALVE, and LATCH VALVE.
THERMAL HEATERS is physical.
TEMPERATURE SENSORS is physical.
HIGH PRESSURE TRANSDUCERS is physical.
HIGH PRESSURE FILL/DRAIN VALVE is physical.
LATCH VALVE is physical.
LATCH VALVE exhibits QUANTITY.
QUANTITY is 0.
MECHANICAL FILTER is physical.
PMA is physical.
PMA exhibits HIGH PRESSURE STAGE and LOW PRESSURE STAGE.
HIGH PRESSURE STAGE consists of PRESSURE TRANSDUCER, TEMPERATURE SENSOR, and PROPORTIONAL CONTROL VALVE.
PRESSURE TRANSDUCER is physical.
TEMPERATURE SENSOR is physical.
PROPORTIONAL CONTROL VALVE is physical.
LOW PRESSURE STAGE consists of LOW PRESSURE TRANSDUCER, TEMPERATURE SENSORS, LOW PRESSURE FILL/VENT VALVE, and DISTRIBUTION MODULE.
LOW PRESSURE TRANSDUCER is physical.
TEMPERATURE SENSORS is physical.
LOW PRESSURE FILL/VENT VALVE is physical.
DISTRIBUTION MODULE is physical.

PPU is physical.
ELECTRIC PROPULSION S/S zooms into TO PROVIDE NEEDED DELTA-V, TO CONTROL TU AND MANAGE PMA, TO PREVENT LOSS OF XENON, TO RUN THE THRUSTER AND SELECT THE CATHODE, TO CONTROL PMA TEMPERATURES, TO COPE WITH THE DEMANDE MASS FLOW RATE FOR THRUSTERS AND CATHODES, TO PROIVDE ISOLATION, and TO RPOTECT AGAINST CONTAMINATION.
TO PROVIDE NEEDED DELTA-V is physical.
TO PROVIDE NEEDED DELTA-V consists of TO PROIVDE ISOLATION, TO RPOTECT AGAINST CONTAMINATION, TO COPE WITH THE DEMANDE MASS FLOW RATE FOR THRUSTERS AND CATHODES, TO CONTROL PMA TEMPERATURES, TO RUN THE THRUSTER AND SELECT THE CATHODE, TO PREVENT LOSS OF XENON, and TO CONTROL TU AND MANAGE PMA.
TO PROIVDE ISOLATION is physical.
TO PROIVDE ISOLATION requires PROPORTIONAL CONTROL VALVE and Ti-6Al-4V tank.
TO RPOTECT AGAINST CONTAMINATION is physical.
TO RPOTECT AGAINST CONTAMINATION requires MECHANICAL FILTER.
TO COPE WITH THE DEMANDE MASS FLOW RATE FOR THRUSTERS AND CATHODES requires ORIFICE.
TO CONTROL PMA TEMPERATURES requires THERMAL HEATERS.
TO RUN THE THRUSTER AND SELECT THE CATHODE is physical.
TO RUN THE THRUSTER AND SELECT THE CATHODE requires SOLENOID VALVE.
TO PREVENT LOSS OF XENON is physical.
TO PREVENT LOSS OF XENON requires GAS FLOW BARRIERS.
TO CONTROL TU AND MANAGE PMA requires PPU.

Diagram 19: Electric propulsion S/S in-zoomed (OPL).

The next subsystem analysed is the avionics one:

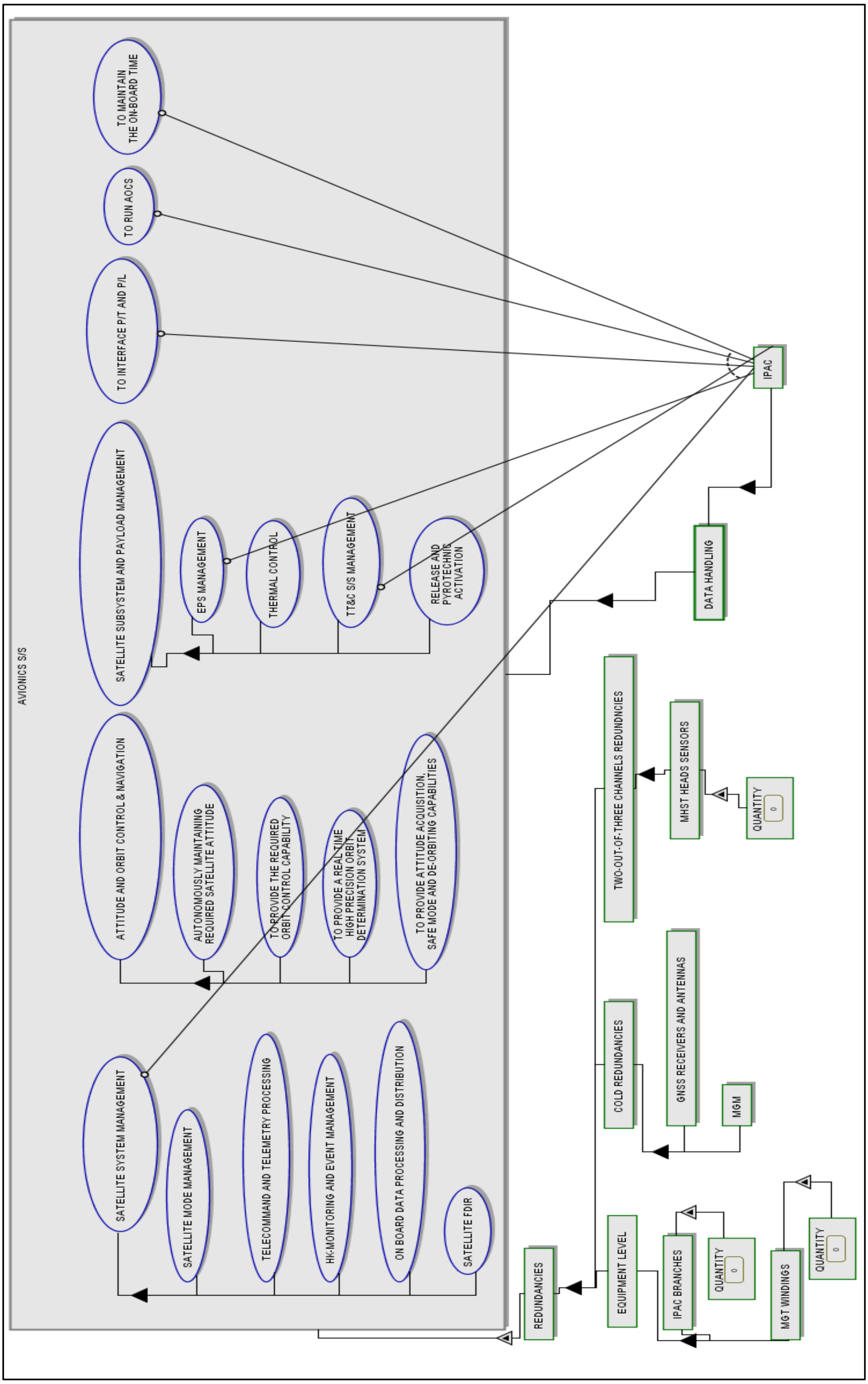


Diagram 20: Avionics S/S in-zoomed (OPD).

AVIONICS S/S is physical.
AVIONICS S/S exhibits REDUNDANCIES, as well as SATELLITE SYSTEM MANAGEMENT, SATELLITE SUBSYSTEM AND PAYLOAD MANAGEMENT, SATELLITE MODE MANAGEMENT, TELECOMMAND AND TELEMETRY PROCESSING, HK-MONITORING AND EVENT MANAGEMENT, ON BOARD DATA PROCESSING AND DISTRIBUTION, SATELLITE FDIR, AUTONOMOUSLY MAINTAINING REQUIRED SATELLITE ATTITUDE, TO PROVIDE THE REQUIRED ORBIT CONTROL CAPABILITY, TO PROVIDE A REAL TIME HIGH PRECISION ORBIT DETERMINATION SYSTEM, TO PROVIDE ATTITUDE ACQUISITION, SAFE MODE AND DE-ORBITING CAPABILITIES, ATTITUDE AND ORBIT CONTROL & NAVIGATION, EPS MANAGEMENT, THERMAL CONTROL, TT&C S/S MANAGEMENT, RELEASE AND PYROTECHNIC ACTIVATION, TO MAINTAIN THE ON-BOARD TIME, TO RUN AOCS, and TO INTERFACE P/T AND P/L.
REDUNDANCIES is physical.
REDUNDANCIES consists of EQUIPMENT LEVEL, COLD REDUNDANCIES, and TWO-OUT-OF-THREE CHANNELS REDUNDNCIES.
EQUIPMENT LEVEL consists of IPAC BRANCHES and MGT WINDINGS.
IPAC BRANCHES is physical.
IPAC BRANCHES exhibits QUANTITY.
QUANTITY is 0.
MGT WINDINGS is physical.
MGT WINDINGS exhibits QUANTITY.
QUANTITY is 0.
COLD REDUNDANCIES is physical.
COLD REDUNDANCIES consists of GNSS RECEIVERS AND ANTENNAS and MGM.
GNSS RECEIVERS AND ANTENNAS is physical.
MGM is physical.
TWO-OUT-OF-THREE CHANNELS REDUNDNCIES is physical.
TWO-OUT-OF-THREE CHANNELS REDUNDNCIES consists of MHST HEADS SENSORS.
MHST HEADS SENSORS is physical.
MHST HEADS SENSORS exhibits QUANTITY.
QUANTITY is 0.
AVIONICS S/S consists of DATA HANDLING.
DATA HANDLING is physical.
DATA HANDLING consists of IPAC.
IPAC is physical.
AVIONICS S/S zooms into SATELLITE SUBSYSTEM AND PAYLOAD MANAGEMENT, ATTITUDE AND ORBIT CONTROL & NAVIGATION, SATELLITE SYSTEM MANAGEMENT, TO INTERFACE P/T AND P/L, TO MAINTAIN THE ON-BOARD TIME, TO RUN AOCS, SATELLITE MODE MANAGEMENT, AUTONOMOUSLY MAINTAINING REQUIRED SATELLITE ATTITUDE, EPS MANAGEMENT, TELECOMMAND AND TELEMETRY PROCESSING, THERMAL CONTROL, TO PROVIDE THE REQUIRED ORBIT CONTROL CAPABILITY, HK-MONITORING AND EVENT MANAGEMENT, TT&C S/S MANAGEMENT, TO PROVIDE A REAL TIME HIGH PRECISION ORBIT DETERMINATION SYSTEM, ON BOARD DATA PROCESSING AND DISTRIBUTION, TO PROVIDE ATTITUDE ACQUISITION, SAFE MODE AND DE-ORBITING CAPABILITIES, RELEASE AND PYROTECHNIC ACTIVATION, and SATELLITE FDIR.
SATELLITE SUBSYSTEM AND PAYLOAD MANAGEMENT is physical.
SATELLITE SUBSYSTEM AND PAYLOAD MANAGEMENT consists of EPS MANAGEMENT, THERMAL CONTROL, TT&C S/S MANAGEMENT, and RELEASE AND PYROTECHNIC ACTIVATION.
EPS MANAGEMENT is physical.
EPS MANAGEMENT requires IPAC.
THERMAL CONTROL is physical.
TT&C S/S MANAGEMENT is physical.
TT&C S/S MANAGEMENT requires IPAC.
RELEASE AND PYROTECHNIC ACTIVATION is physical.
ATTITUDE AND ORBIT CONTROL & NAVIGATION is physical.
ATTITUDE AND ORBIT CONTROL & NAVIGATION consists of AUTONOMOUSLY MAINTAINING REQUIRED SATELLITE ATTITUDE, TO PROVIDE THE REQUIRED ORBIT CONTROL CAPABILITY, TO PROVIDE A REAL TIME HIGH PRECISION ORBIT DETERMINATION SYSTEM, and TO PROVIDE ATTITUDE ACQUISITION, SAFE MODE AND DE-ORBITING CAPABILITIES.
AUTONOMOUSLY MAINTAINING REQUIRED SATELLITE ATTITUDE is physical.
TO PROVIDE THE REQUIRED ORBIT CONTROL CAPABILITY is physical.
TO PROVIDE A REAL TIME HIGH PRECISION ORBIT DETERMINATION SYSTEM is physical.
TO PROVIDE ATTITUDE ACQUISITION, SAFE MODE AND DE-ORBITING CAPABILITIES is physical.
SATELLITE SYSTEM MANAGEMENT is physical.
SATELLITE SYSTEM MANAGEMENT consists of SATELLITE MODE MANAGEMENT, TELECOMMAND AND TELEMETRY PROCESSING, HK-MONITORING AND EVENT MANAGEMENT, ON BOARD DATA PROCESSING AND DISTRIBUTION, and SATELLITE FDIR.

SATELLITE MODE MANAGEMENT is physical.
TELECOMMAND AND TELEMETRY PROCESSING is physical.
HK-MONITORING AND EVENT MANAGEMENT is physical.
ON BOARD DATA PROCESSING AND DISTRIBUTION is physical.
SATELLITE FDIR is physical.
SATELLITE SYSTEM MANAGEMENT requires IPAC.
TO INTERFACE P/T AND P/L is physical.
TO INTERFACE P/T AND P/L requires IPAC.
TO MAINTAIN THE ON-BOARD TIME is physical.
TO MAINTAIN THE ON-BOARD TIME requires IPAC.
TO RUN AOCS is physical.
TO RUN AOCS requires IPAC.

Diagram 21: Avionics S/S in-zoomed (OPL).

The following diagram is the functional architecture of the Bus Module which is a part of the thermo-structure subsystem, as showed in the platform physical architecture diagram.

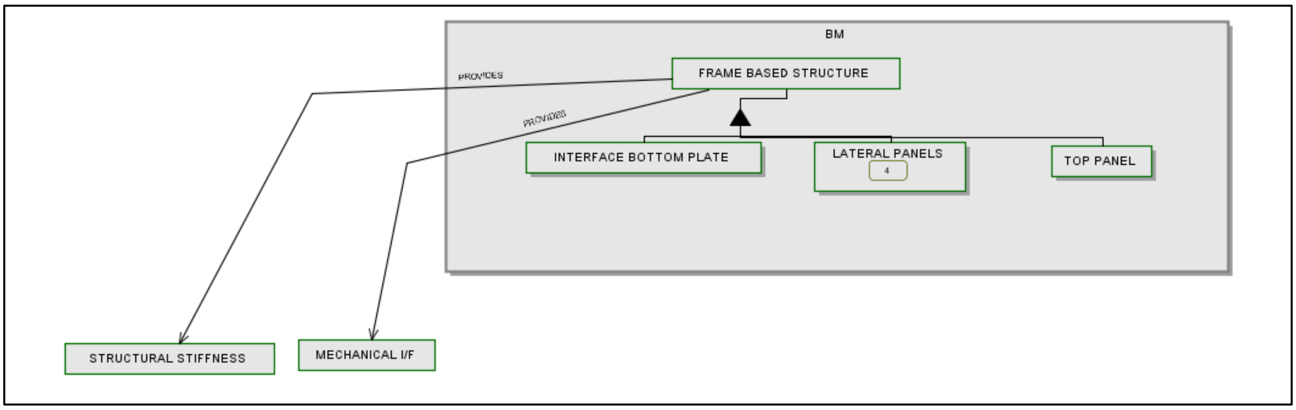


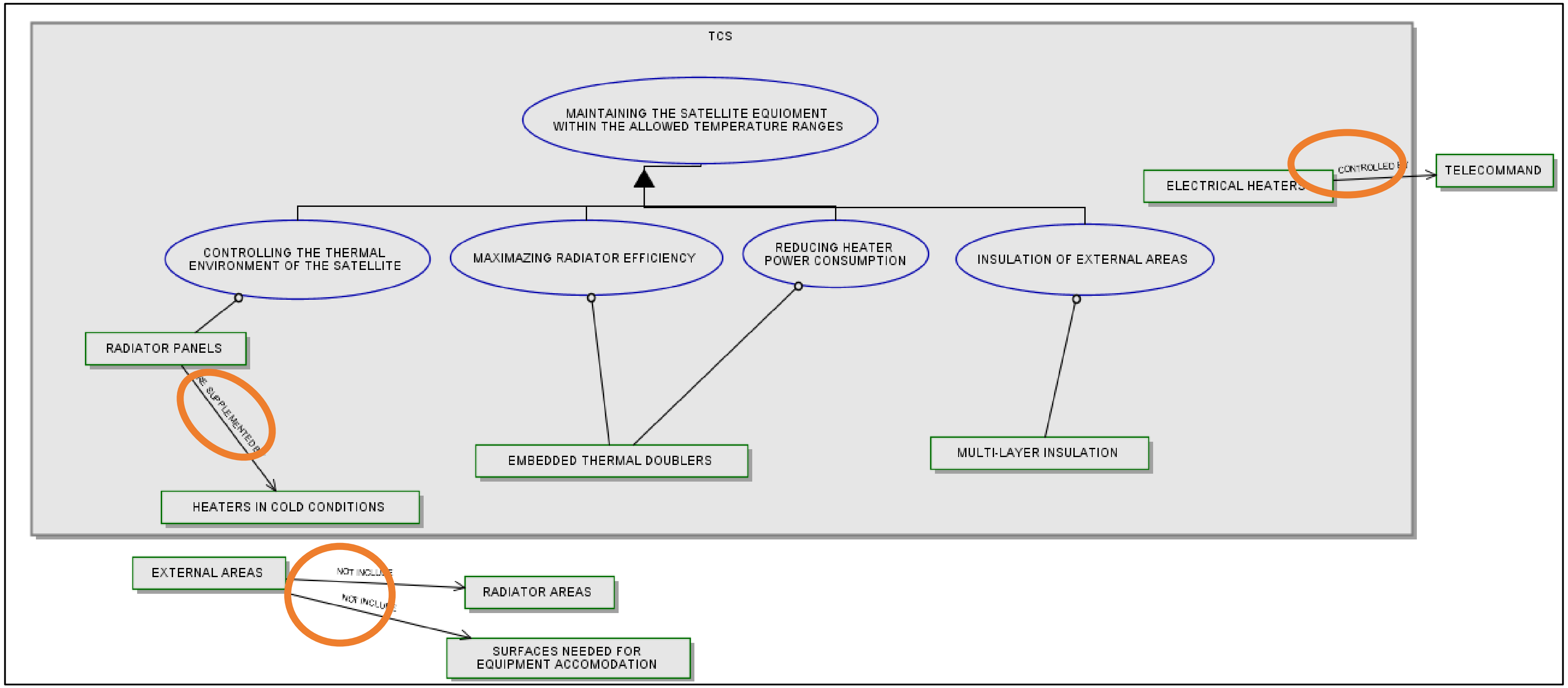
Diagram 22: BM in-zoomed (OPD).

Its equivalent OPL is:

BM is physical.
BM consists of INTERFACE BOTTOM PLATE, LATERAL PANELS, TOP PANEL, and FRAME BASED STRUCTURE.
BM zooms into FRAME BASED STRUCTURE, TOP PANEL, LATERAL PANELS, and INTERFACE BOTTOM PLATE.
FRAME BASED STRUCTURE consists of INTERFACE BOTTOM PLATE, LATERAL PANELS, and TOP PANEL.
INTERFACE BOTTOM PLATE is physical.
LATERAL PANELS is physical.
LATERAL PANELS is 4.
TOP PANEL is physical.
FRAME BASED STRUCTURE PROVIDES MECHANICAL I/F.
FRAME BASED STRUCTURE PROVIDES STRUCTURAL STIFFNESS.

Diagram 23: BM in-zoomed (OPL).

The other part of the thermo-structure subsystem is represented by the thermal control system and the textual part is shown under the corresponding OPD:



TELECOMMAND is physical.
EXTERNAL AREAS is physical.
EXTERNAL AREAS NOT INCLUDE RADIATOR AREAS.
EXTERNAL AREAS NOT INCLUDE SURFACES NEEDED FOR EQUIPMENT ACCOMODATION.
RADIATOR AREAS is physical.
SURFACES NEEDED FOR EQUIPMENT ACCOMODATION is physical.
TCS is physical.
TCS exhibits CONTROLLING THE THERMAL ENVIRONMENT OF THE SATELLITE, MAXIMAZING RADIATOR EFFICIENCY, REDUCING HEATER POWER CONSUMPTION, INSULATION OF EXTERNAL AREAS, and MAINTAINING THE SATELLITE EQUIOMENT WITHIN THE ALLOWED TEMPERATURE RANGES.
TCS consists of RADIATOR PANELS, HEATERS IN COLD CONDITIONS, EMBEDDED THERMAL DOUBLERS, MULTI-LAYER INSULATION, and ELECTRICAL HEATERS.
TCS zooms into ELECTRICAL HEATERS, MULTI-LAYER INSULATION, EMBEDDED THERMAL DOUBLERS, HEATERS IN COLD CONDITIONS, and RADIATOR PANELS, as well as MAINTAINING THE SATELLITE EQUIOMENT WITHIN THE ALLOWED TEMPERATURE RANGES, REDUCING HEATER POWER CONSUMPTION, MAXIMAZING RADIATOR EFFICIENCY, CONTROLLING THE THERMAL ENVIRONMENT OF THE SATELLITE, and INSULATION OF EXTERNAL AREAS.

ELECTRICAL HEATERS is physical.
ELECTRICAL HEATERS CONTROLLED BY TELECOMMAND.
MULTI-LAYER INSULATION is physical.
EMBEDDED THERMAL DOUBLERS is physical.
HEATERS IN COLD CONDITIONS is physical.
RADIATOR PANELS is physical.
RADIATOR PANELS ARE SUPPLEMENTED BY HEATERS IN COLD CONDITIONS.
MAINTAINING THE SATELLITE EQUIOMENT WITHIN THE ALLOWED TEMPERATURE RANGES consists of CONTROLLING THE THERMAL ENVIRONMENT OF THE SATELLITE, MAXIMAZING RADIATOR EFFICIENCY, REDUCING HEATER POWER CONSUMPTION, and INSULATION OF EXTERNAL AREAS.

CONTROLLING THE THERMAL ENVIRONMENT OF THE SATELLITE requires RADIATOR PANELS.
MAXIMAZING RADIATOR EFFICIENCY requires EMBEDDED THERMAL DOUBLERS.
REDUCING HEATER POWER CONSUMPTION requires EMBEDDED THERMAL DOUBLERS.
INSULATION OF EXTERNAL AREAS requires MULTI-LAYER INSULATION.

Diagram 24: TCS in-zoomed (OPD and OPL).

The links circled in orange represent a type of structural link called "tagged structural link"; they leave you the freedom to specify what kind of structural relationship you are expressing, by allowing you to add a textual part on the arrow. In the relative OPL the structure of the sentence foresees "source thing – tag – destination thing".

Next OPD is the functional architecture of the Electrical Power System. Equivalent OPL provides the textual equivalent part:

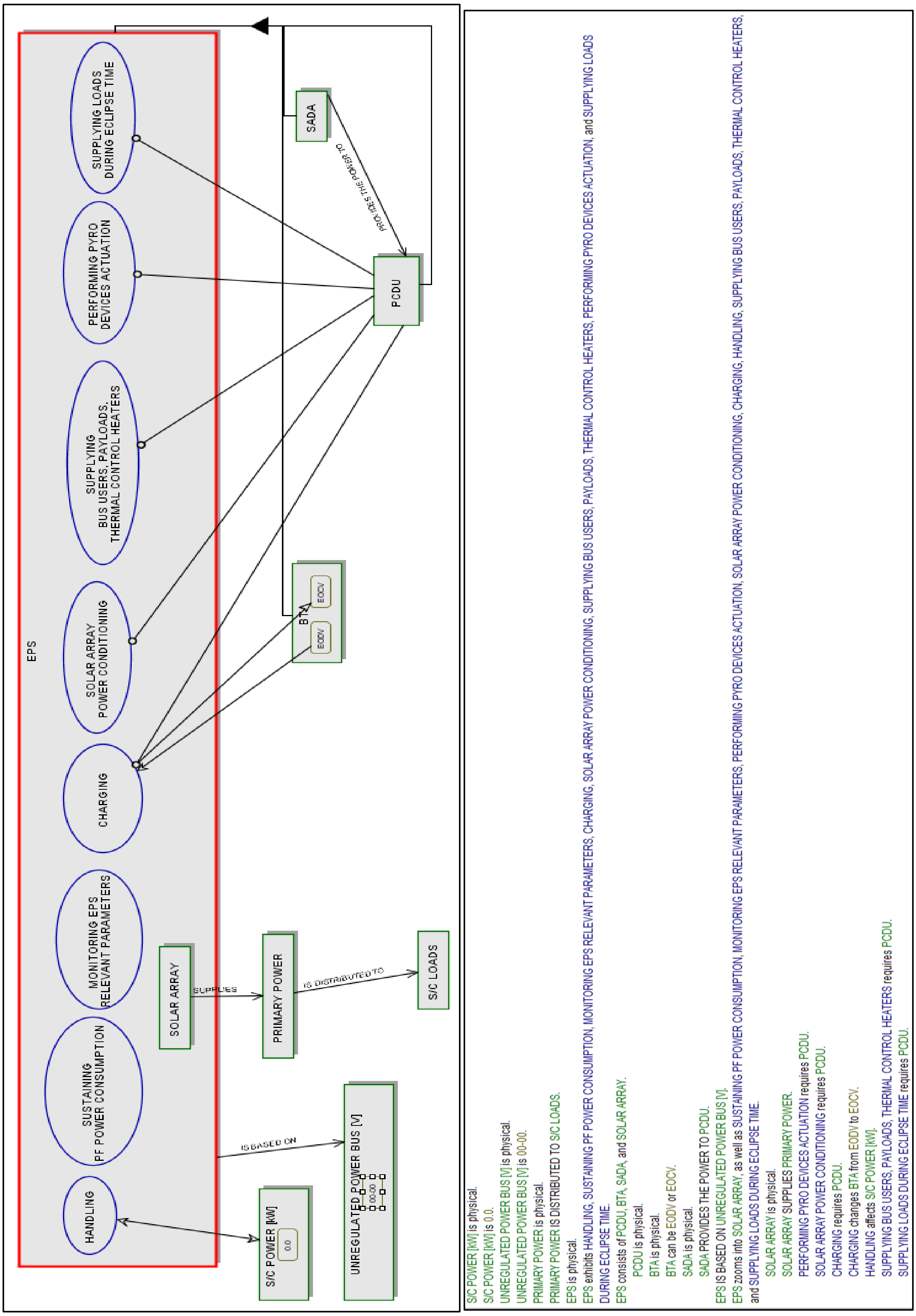
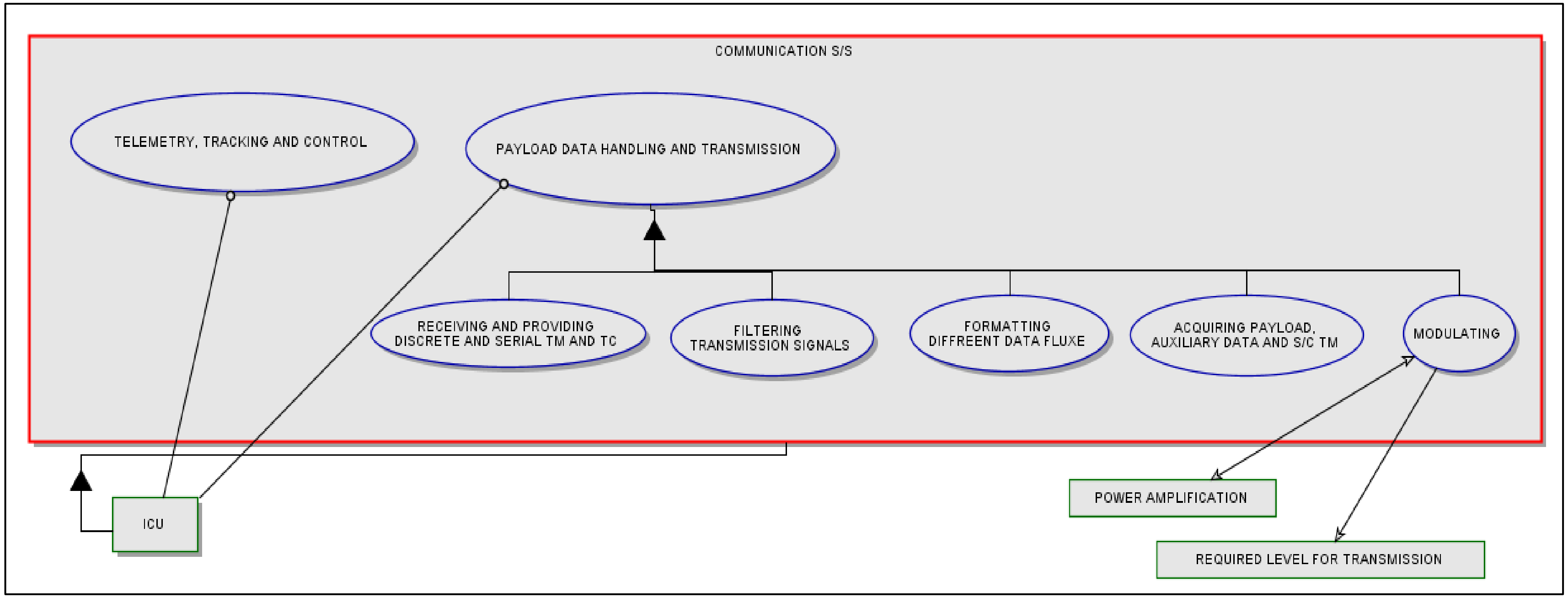


Diagram 25: EPS in-zoomed (OPD and OPL).

The last subsystem in-zoom representation is that of the Communication Subsystem:



COMMUNICATION S/S is physical.
COMMUNICATION S/S exhibits TELEMETRY, TRACKING AND CONTROL, MODULATING, ACQUIRING PAYLOAD, AUXILIARY DATA AND S/C TM, FORMATTING DIFFREENT DATA FLUXE, FILTERING TRANSMISSION SIGNALS, RECEIVING AND PROVIDING DISCRETE AND SERIAL TM AND TC, and PAYLOAD DATA HANDLING AND TRANSMISSION.
COMMUNICATION S/S consists of ICU.
    ICU is physical.
COMMUNICATION S/S zooms into PAYLOAD DATA HANDLING AND TRANSMISSION, TELEMETRY, TRACKING AND CONTROL, FORMATTING DIFFREENT DATA FLUXE, ACQUIRING PAYLOAD, AUXILIARY DATA AND S/C TM, MODULATING, RECEIVING AND PROVIDING DISCRETE AND SERIAL TM AND TC, and FILTERING TRANSMISSION SIGNALS.
    PAYLOAD DATA HANDLING AND TRANSMISSION is physical.
    PAYLOAD DATA HANDLING AND TRANSMISSION consists of MODULATING, ACQUIRING PAYLOAD, AUXILIARY DATA AND S/C TM, FORMATTING DIFFREENT DATA FLUXE, FILTERING TRANSMISSION SIGNALS, and RECEIVING AND PROVIDING DISCRETE AND SERIAL TM AND TC.
        MODULATING is physical.
        MODULATING affects POWER AMPLIFICATION.
        MODULATING yields REQUIRED LEVEL FOR TRANSMISSION.
        FORMATTING DIFFREENT DATA FLUXE is physical.
        FILTERING TRANSMISSION SIGNALS is physical.
        RECEIVING AND PROVIDING DISCRETE AND SERIAL TM AND TC is physical.
    PAYLOAD DATA HANDLING AND TRANSMISSION requires ICU.
    TELEMETRY, TRACKING AND CONTROL is physical.
    TELEMETRY, TRACKING AND CONTROL requires ICU.

Diagram 26: Communication S/S in-zoomed (OPD and OPL).

4.3.8 PLATiNO 1 mission phases

PLATiNO 1 satellite should perform two operative phases for PLATiNO 1 mission, as displayed in the following diagram:

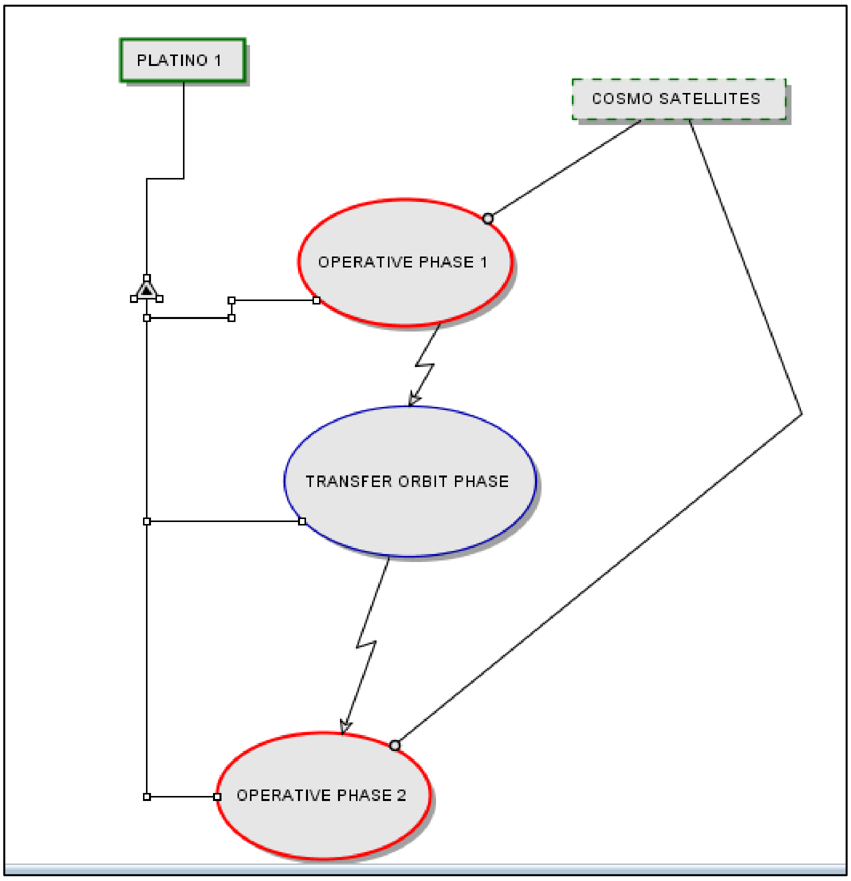


Diagram 27: PLATiNO 1 operative phases (OPD).

These phases represents how PLATiNO 1 payload will achieve its scope and what, in particular, its functions will be.

It is important to note that in this OPD the exhibition/characterization link is used in a different way than in previous diagrams: it relates an object (PLATiNO 1) with some processes. It is another feature of this link and it means that the object in question is characterized by the functions with it is related.

From this OPD even it emerges that the operative phases of PLATiNO 1 satellite cannot be performed without the existence of COSMO SKYMED satellite, that is the constellation which supports PLATiNO 1 mission. COSMO SKYMED satellite is not part of the considered system, that is PLATiNO 1 satellite. For this reason, the COSMO SKYMED square has a dashed outline.

The following OPL reports this information writing that COSMO SKYMED “is environmental”:

COSMO SATELLITES is environmental and physical.
PLATINO 1 is physical.
OPERATIVE PHASE 1 is physical.
OPERATIVE PHASE 1 requires COSMO SATELLITES.
OPERATIVE PHASE 1 invokes TRANSFER ORBIT PHASE.
OPERATIVE PHASE 2 is physical.
OPERATIVE PHASE 2 requires COSMO SATELLITES.
TRANSFER ORBIT PHASE is physical.
TRANSFER ORBIT PHASE invokes OPERATIVE PHASE 2.

Diagram 28: PLATiNO 1 operative phases (OPL).

The operative phase one is represented below trough an in-zoom and it is made up by the nominal mission phase. This process cannot exist alone, but its completion requires the immediate beginning of the consequent one, that is the “opportunity mission phase”.

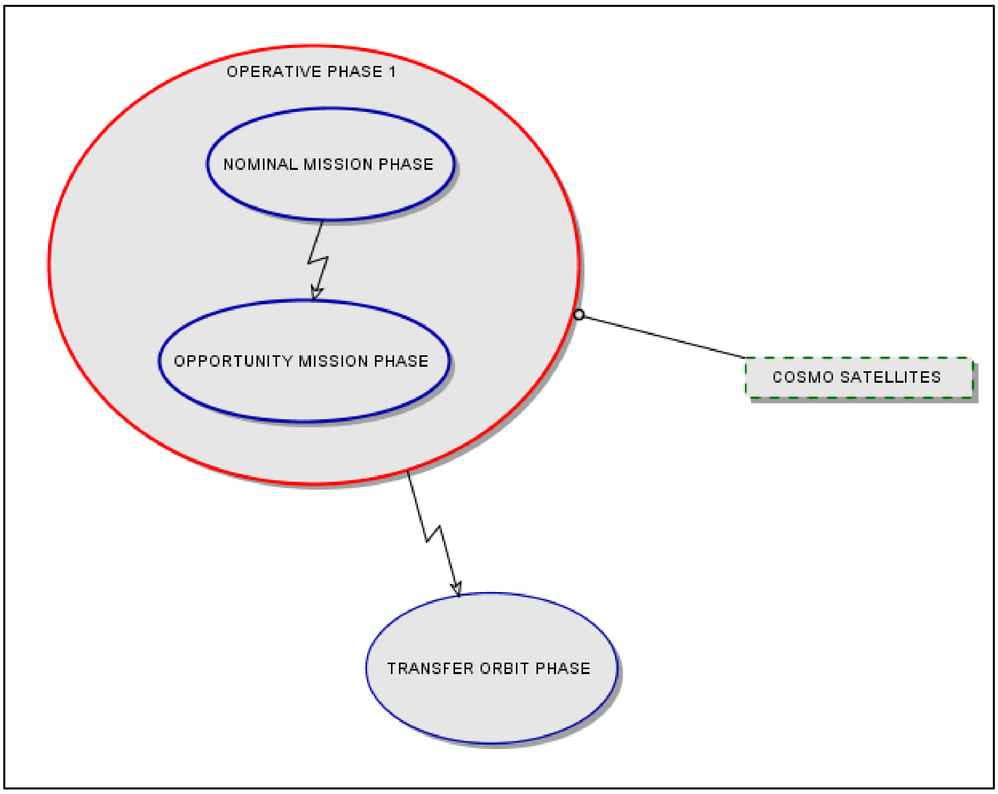


Diagram 29: Operative phase 1 in-zoomed (OPD).

The corresponding OPL is:

COSMO SATELLITES is environmental and physical.
TRANSFER ORBIT PHASE is physical.
OPERATIVE PHASE 1 is physical.
OPERATIVE PHASE 1 consists of NOMINAL MISSION PHASE and OPPORTUNITY MISSION PHASE.
OPERATIVE PHASE 1 requires COSMO SATELLITES.
OPERATIVE PHASE 1 invokes TRANSFER ORBIT PHASE.
OPERATIVE PHASE 1 zooms into NOMINAL MISSION PHASE and OPPORTUNITY MISSION PHASE.
NOMINAL MISSION PHASE is physical.
NOMINAL MISSION PHASE invokes OPPORTUNITY MISSION PHASE.
OPPORTUNITY MISSION PHASE is physical.

Diagram 30: PLATiNO 1 operative phase 1 in-zoomed (OPL).

Therefore, the operative phase 1 consists of the nominal mission phase and the opportunity mission phase performed in this order, as it emerges even from the previous diagram. In turn, the nominal mission phase can be specified with another in-zoom:

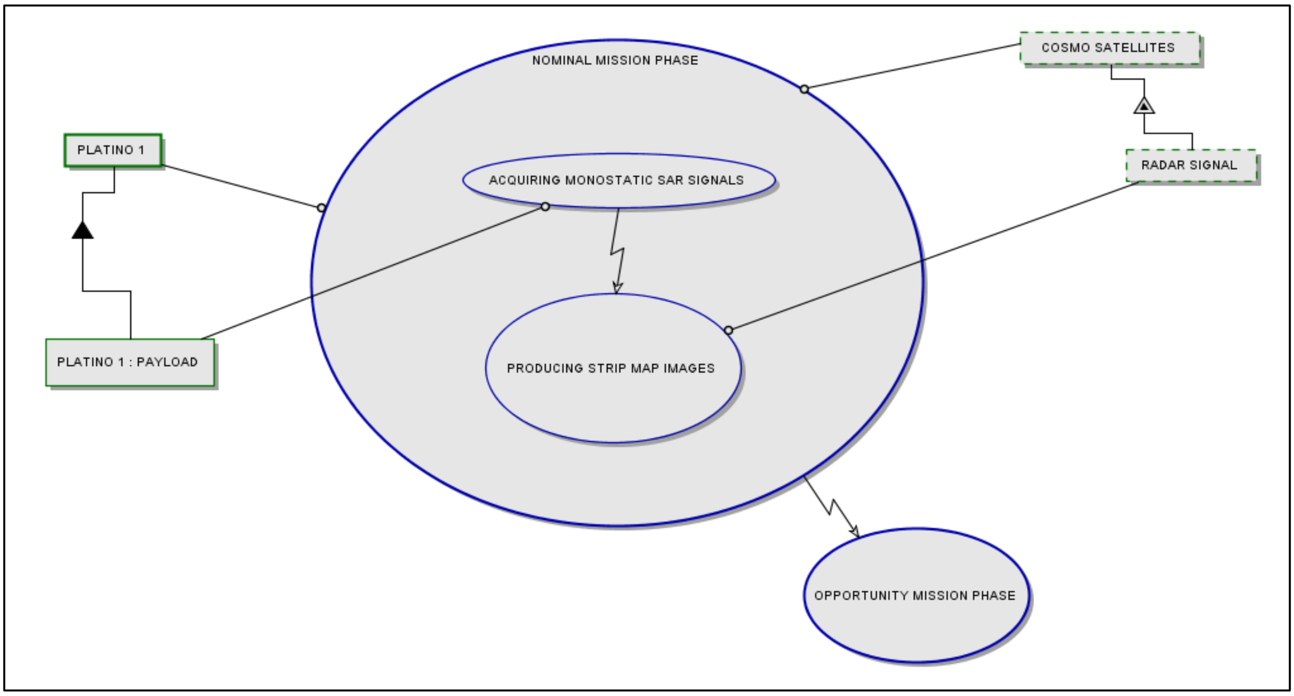


Diagram 31: Nominal mission phase in-zoomed (OPD).

The equivalent textual form is:

PLATINO 1 is physical.
PLATINO 1 consists of PLATINO 1 : PAYLOAD.
PLATINO 1 : PAYLOAD is physical.
COSMO SATELLITES is environmental and physical.
COSMO SATELLITES exhibits RADAR SIGNAL.
RADAR SIGNAL is environmental and physical.
OPPORTUNITY MISSION PHASE is physical.
NOMINAL MISSION PHASE is physical.
NOMINAL MISSION PHASE consists of ACQUIRING MONOSTATIC SAR SIGNALS and PRODUCING STRIP MAP IMAGES.
NOMINAL MISSION PHASE requires PLATINO 1 and COSMO SATELLITES.
NOMINAL MISSION PHASE invokes OPPORTUNITY MISSION PHASE.
NOMINAL MISSION PHASE zooms into ACQUIRING MONOSTATIC SAR SIGNALS and PRODUCING STRIP MAP IMAGES.
ACQUIRING MONOSTATIC SAR SIGNALS is physical.
ACQUIRING MONOSTATIC SAR SIGNALS requires PLATINO 1 : PAYLOAD.
ACQUIRING MONOSTATIC SAR SIGNALS invokes PRODUCING STRIP MAP IMAGES.
PRODUCING STRIP MAP IMAGES is physical.
PRODUCING STRIP MAP IMAGES requires RADAR SIGNAL.

Diagram 32: Nominal mission phase in-zoomed (OPL).

The consequent phase is the opportunity mission phase which is performed in the following way:

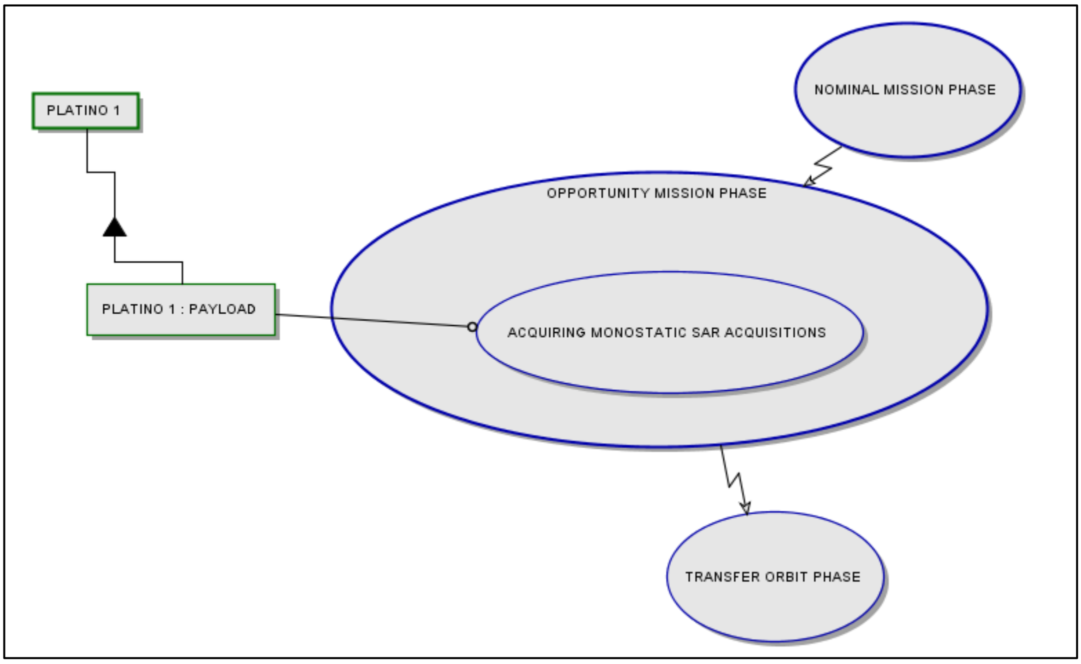


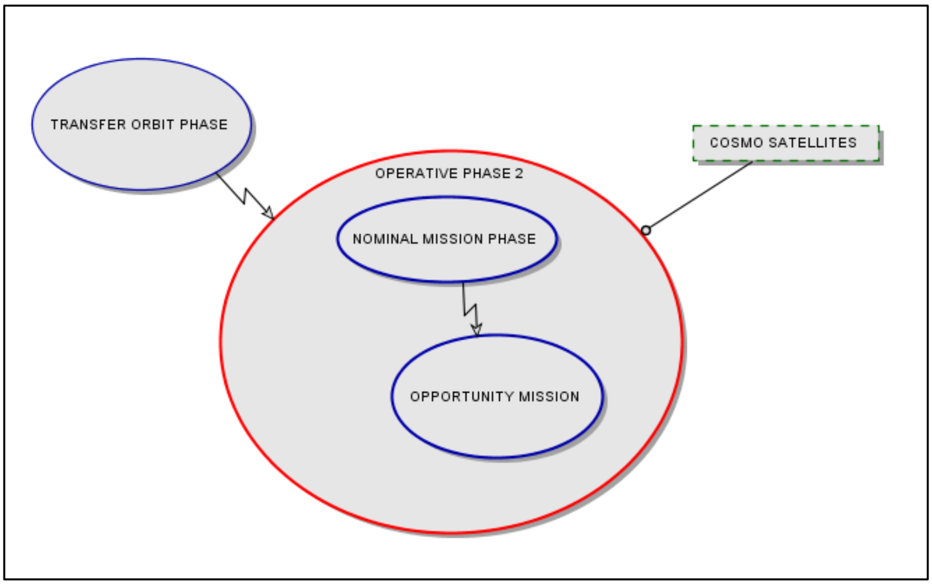
Diagram 33: Opportunity mission phase in-zoomed (OPD).

Textually, it can be explained as:

PLATINO 1 is physical.
PLATINO 1 consists of PLATINO 1 : PAYLOAD.
PLATINO 1 : PAYLOAD is physical.
TRANSFER ORBIT PHASE is physical.
NOMINAL MISSION PHASE is physical.
NOMINAL MISSION PHASE invokes OPPORTUNITY MISSION PHASE.
OPPORTUNITY MISSION PHASE is physical.
OPPORTUNITY MISSION PHASE consists of ACQUIRING MONOSTATIC SAR ACQUISITIONS.
OPPORTUNITY MISSION PHASE invokes TRANSFER ORBIT PHASE.
OPPORTUNITY MISSION PHASE zooms into ACQUIRING MONOSTATIC SAR ACQUISITIONS.
ACQUIRING MONOSTATIC SAR ACQUISITIONS is physical.
ACQUIRING MONOSTATIC SAR ACQUISITIONS requires PLATINO 1 : PAYLOAD.

Diagram 34: Opportunity mission phase in-zoomed (OPL).

After a transfer orbit phase, PLATiNO 1 satellite should perform another operative phase which has the same structure of the first one:



COSMO SATELLITES is environmental and physical.
TRANSFER ORBIT PHASE is physical.
TRANSFER ORBIT PHASE invokes OPERATIVE PHASE 2.
OPERATIVE PHASE 2 is physical.
OPERATIVE PHASE 2 consists of NOMINAL MISSION PHASE and OPPORTUNITY MISSION.
OPERATIVE PHASE 2 requires COSMO SATELLITES.
OPERATIVE PHASE 2 zooms into NOMINAL MISSION PHASE and OPPORTUNITY MISSION.
NOMINAL MISSION PHASE is physical.
NOMINAL MISSION PHASE invokes OPPORTUNITY MISSION.
OPPORTUNITY MISSION is physical.

Diagram 35: Operative phase 2 in-zoomed (OPD and OPL).

But nominal mission phase in-zoom presents some differences respect to the precious one:

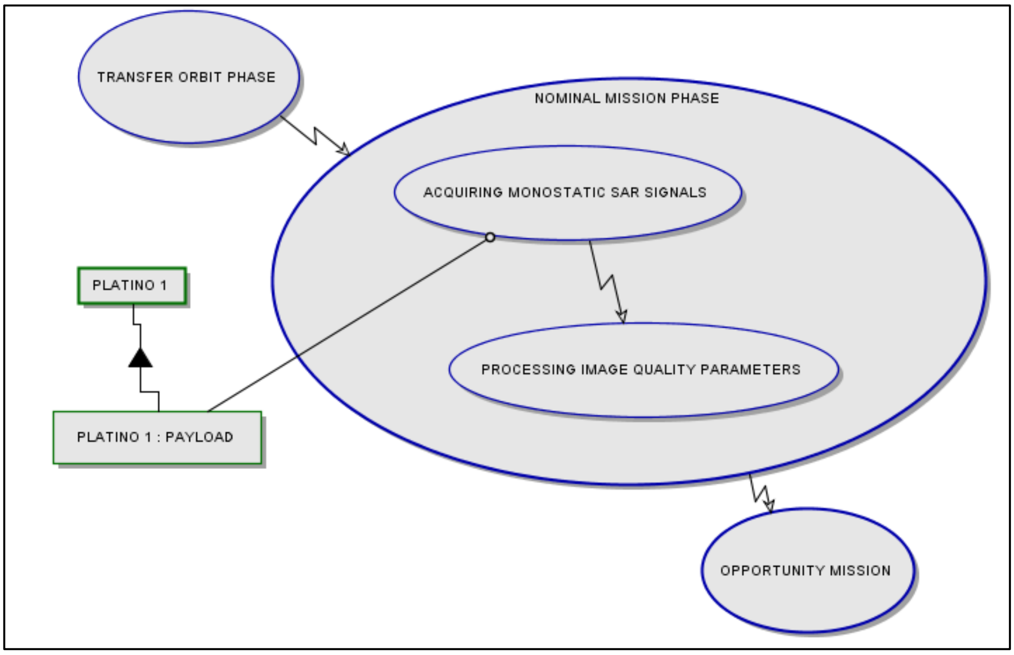


Diagram 36: Nominal mission phase in-zoomed (OPD).

The related OPL is:

PLATINO 1 is physical.
PLATINO 1 consists of PLATINO 1 : PAYLOAD.
    PLATINO 1 : PAYLOAD is physical.
TRANSFER ORBIT PHASE is physical.
TRANSFER ORBIT PHASE invokes NOMINAL MISSION PHASE.
OPPORTUNITY MISSION is physical.
NOMINAL MISSION PHASE is physical.
NOMINAL MISSION PHASE consists of ACQUIRING MONOSTATIC SAR SIGNALS and PROCESSING IMAGE QUALITY PARAMETERS.
NOMINAL MISSION PHASE invokes OPPORTUNITY MISSION.
NOMINAL MISSION PHASE zooms into ACQUIRING MONOSTATIC SAR SIGNALS and PROCESSING IMAGE QUALITY PARAMETERS.
    ACQUIRING MONOSTATIC SAR SIGNALS is physical.
    ACQUIRING MONOSTATIC SAR SIGNALS requires PLATINO 1 : PAYLOAD.
    ACQUIRING MONOSTATIC SAR SIGNALS invokes PROCESSING IMAGE QUALITY PARAMETERS.
    PROCESSING IMAGE QUALITY PARAMETERS is physical.

Diagram 37: Nominal mission phase in-zoomed (OPL).

The consequent opportunity mission phase OPD is:

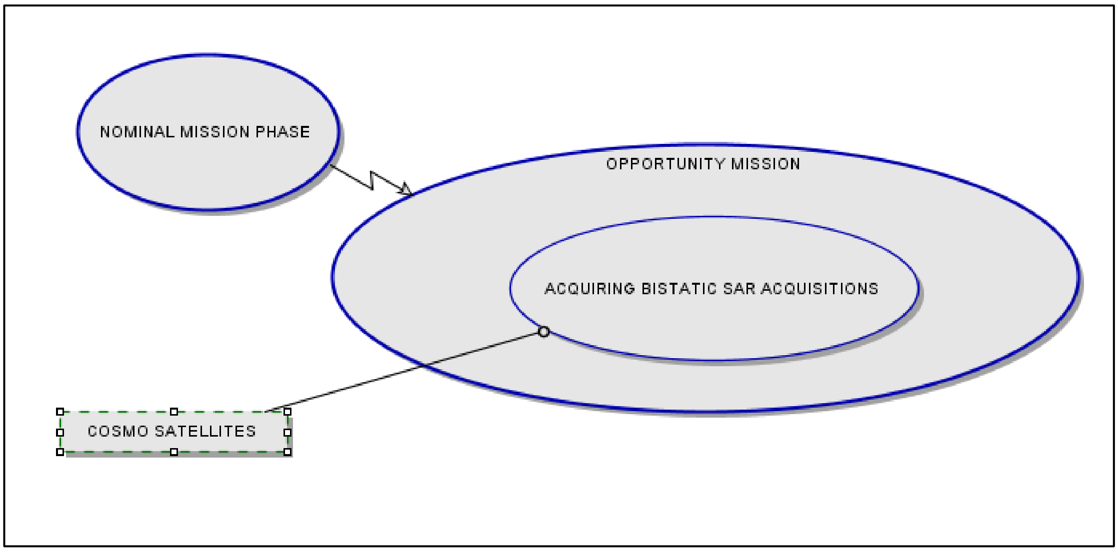


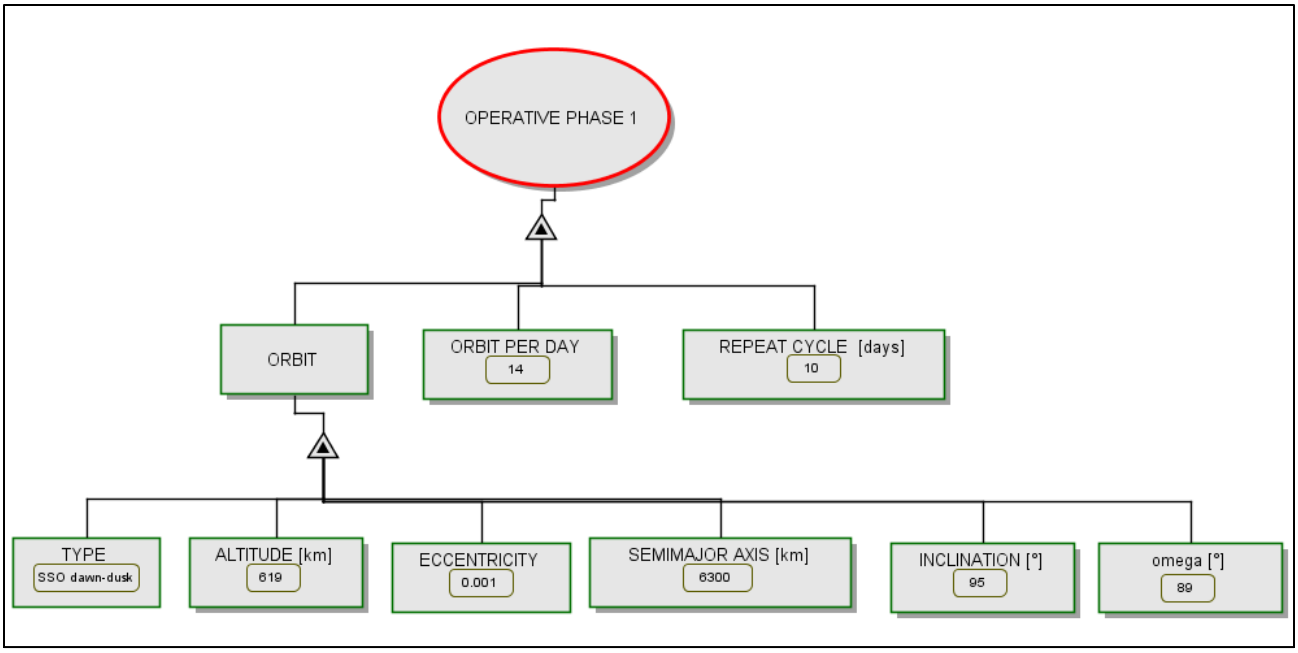
Diagram 38: Opportunity mission in-zoomed (OPD).

Whereas the corresponding OPL is:

COSMO SATELLITES is environmental and physical.
NOMINAL MISSION PHASE is physical.
NOMINAL MISSION PHASE invokes OPPORTUNITY MISSION.
OPPORTUNITY MISSION is physical.
OPPORTUNITY MISSION consists of ACQUIRING BISTATIC SAR ACQUISITIONS.
OPPORTUNITY MISSION zooms into ACQUIRING BISTATIC SAR ACQUISITIONS.
    ACQUIRING BISTATIC SAR ACQUISITIONS is physical.
    ACQUIRING BISTATIC SAR ACQUISITIONS requires COSMO SATELLITES.

Diagram 39: Opportunity mission in-zoomed (OPL).

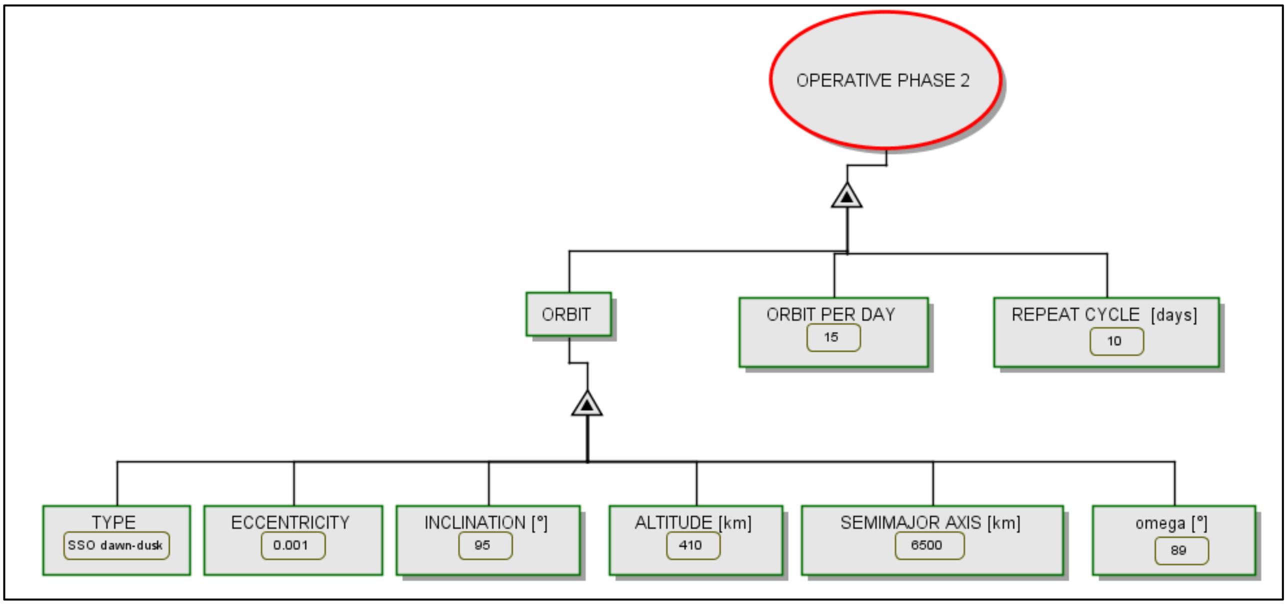
It has been created two other views in order to specify the physical characteristics of the two operative phases:



TYPE is SSO dawn-dusk.
ALTITUDE [km] is physical.
ALTITUDE [km] is 619.
ECCENTRICITY is 0.001.
SEMIMAJOR AXIS [km] is physical.
SEMIMAJOR AXIS [km] is 6300.
INCLINATION [°] is physical.
INCLINATION [°] is 95.
omega [°] is physical.
omega [°] is 89.
OPERATIVE PHASE 1 is physical.
OPERATIVE PHASE 1 exhibits ORBIT, ORBIT PER DAY, and REPEAT CYCLE [days].
    ORBIT is physical.
    ORBIT exhibits TYPE, ALTITUDE [km], ECCENTRICITY, SEMIMAJOR AXIS [km], INCLINATION [°], and omega [°].
    ORBIT PER DAY is physical.
    ORBIT PER DAY is 14.
    REPEAT CYCLE [days] is physical.
    REPEAT CYCLE [days] is 10.
OPERATIVE PHASE 1 zooms into NOMINAL MISSION PHASE and OPPORTUNITY MISSION PHASE.
    NOMINAL MISSION PHASE is physical.
    OPPORTUNITY MISSION PHASE is physical.

Diagram 40: Operative phase 1 characterization (OPD and OPL).

The use of the exhibition/characterization link is justified by the fact that orbit, orbit per day and repeat cycle are objects to which it is allowed to attribute a value. The same for the characteristics of the orbit in terms of type, eccentricity, inclination, altitude, semimajor axis and argument of periaxis.



TYPE is SSO dawn-dusk.
ECCENTRICITY is 0.001.
INCLINATION [°] is physical.
INCLINATION [°] is 95.
ALTITUDE [km] is physical.
ALTITUDE [km] is 410.
SEMIMAJOR AXIS [km] is physical.
SEMIMAJOR AXIS [km] is 6500.
omega [°] is physical.
omega [°] is 89.
OPERATIVE PHASE 2 is physical.
OPERATIVE PHASE 2 exhibits ORBIT, ORBIT PER DAY, and REPEAT CYCLE [days].
    ORBIT is physical.
    ORBIT exhibits TYPE, ECCENTRICITY, INCLINATION [°], ALTITUDE [km], SEMIMAJOR AXIS [km], and omega [°].
    ORBIT PER DAY is physical.
    ORBIT PER DAY is 15.
    REPEAT CYCLE [days] is physical.
    REPEAT CYCLE [days] is 10.
OPERATIVE PHASE 2 zooms into NOMINAL MISSION PHASE and OPPORTUNITY MISSION.
    NOMINAL MISSION PHASE is physical.
    OPPORTUNITY MISSION is physical.

Diagram 41: Operative phase 2 characterization (OPD and OPL).

4.3.9 PLATiNO Platform S/S mass budget

The last type of representation concerns the mass budget of each subsystem. It has been used once again the exhibition/characterization link because the showed subsystems' features have a value. For each subsystem its units are represented and, for each unit, it is displayed its quantity, its nominal mass, the margin considered and the conservative mass obtained. The diagrams even show the total value of the nominal mass and of the conservative one.

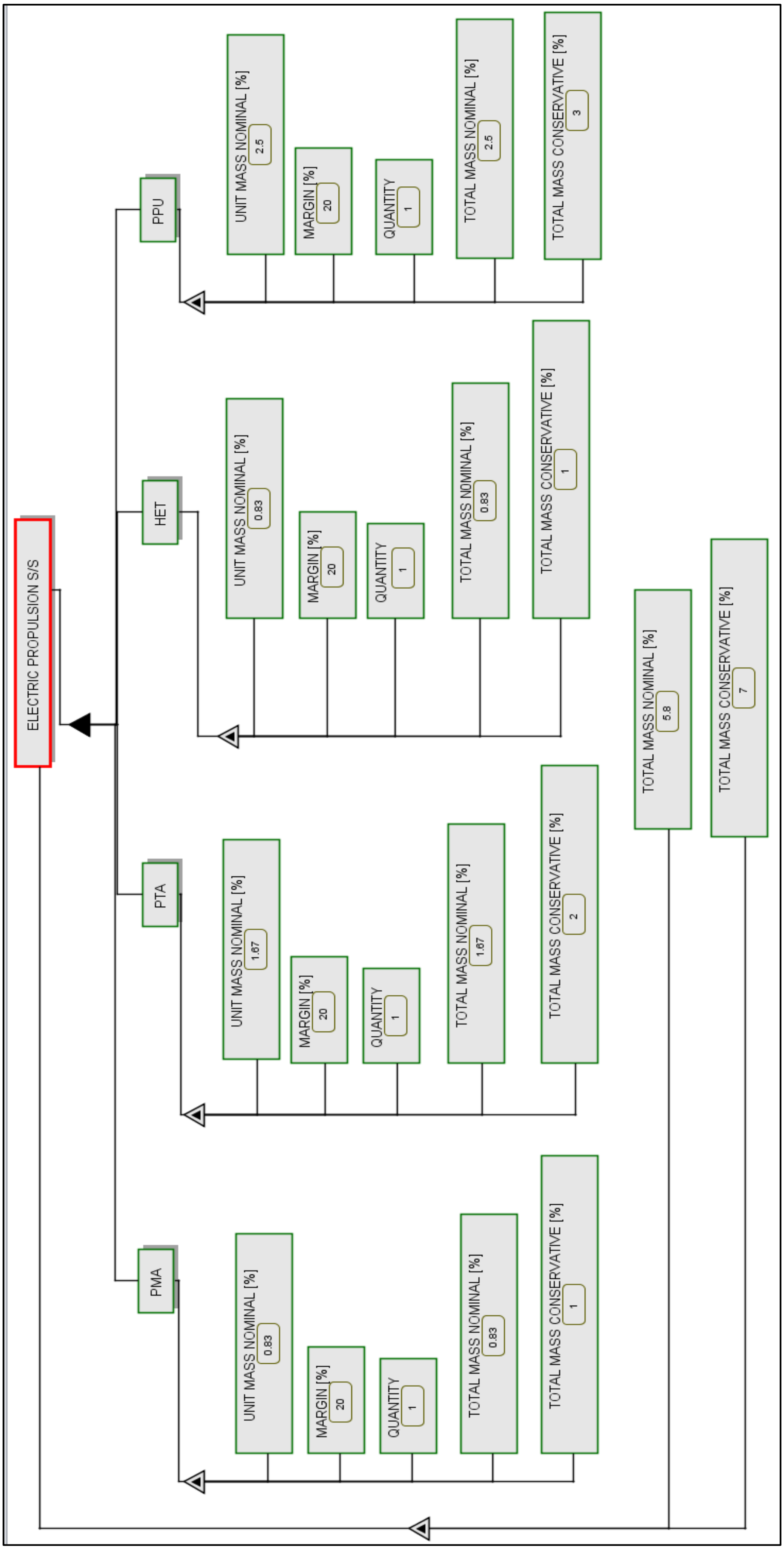
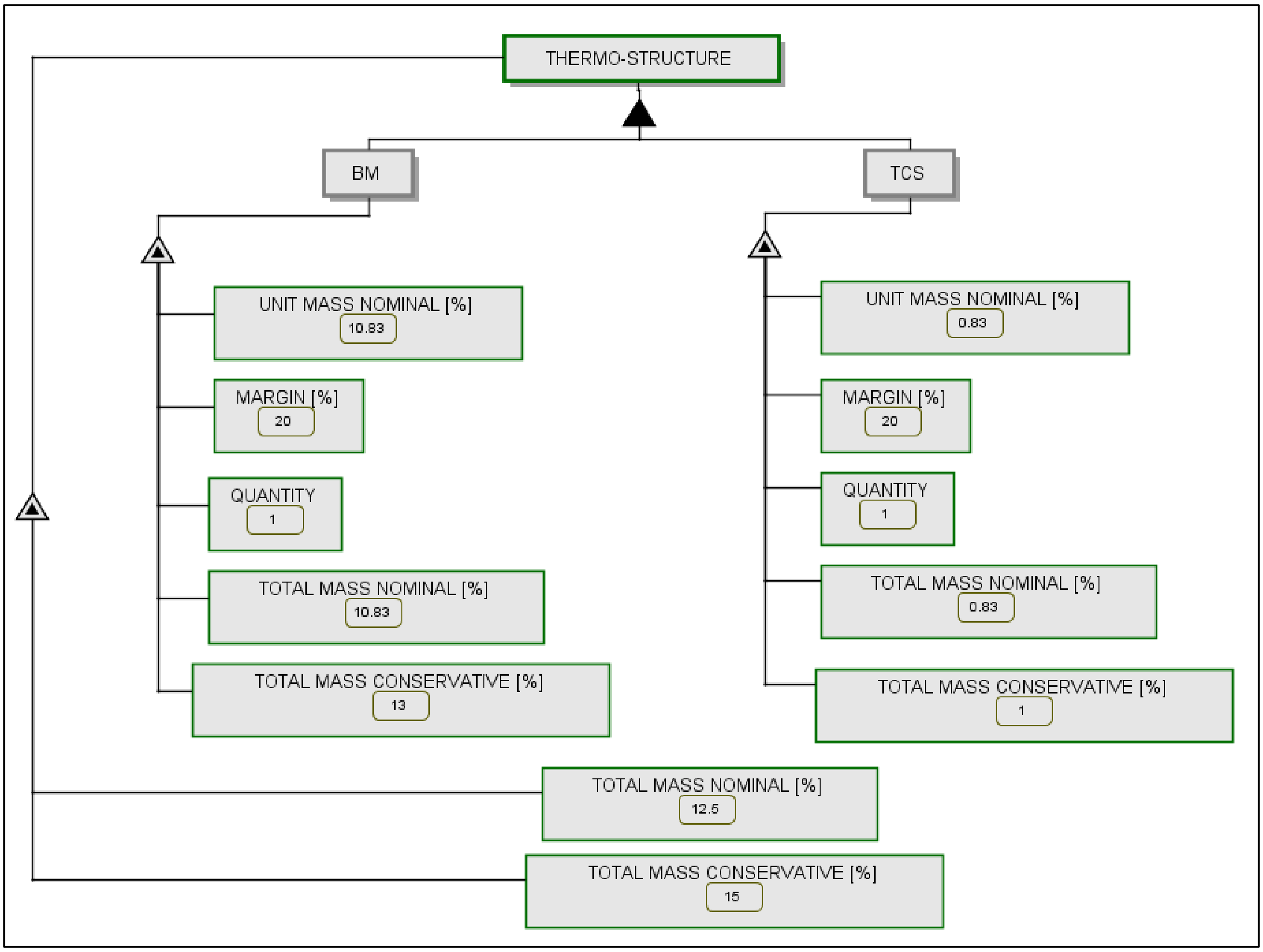


Diagram 42: Electric propulsion S/S mass budget (OPD).

ELECTRIC PROPULSION S/S is physical.
ELECTRIC PROPULSION S/S exhibits TOTAL MASS NOMINAL [%] and TOTAL MASS CONSERVATIVE [%].
    TOTAL MASS NOMINAL [%] is 5.8.
    TOTAL MASS CONSERVATIVE [%] is 7.
ELECTRIC PROPULSION S/S consists of HET, PTA, PMA, and PPU.
    HET is physical.
    HET exhibits UNIT MASS NOMINAL [%], MARGIN [%], QUANTITY, TOTAL MASS NOMINAL [%], and TOTAL MASS CONSERVATIVE [%].
        UNIT MASS NOMINAL [%] is 0.83.
        MARGIN [%] is 20.
        QUANTITY is 1.
        TOTAL MASS NOMINAL [%] is 0.83.
        TOTAL MASS CONSERVATIVE [%] is 1.
    PTA is physical.
    PTA exhibits UNIT MASS NOMINAL [%], MARGIN [%], QUANTITY, TOTAL MASS NOMINAL [%], and TOTAL MASS CONSERVATIVE [%].
        UNIT MASS NOMINAL [%] is 1.67.
        MARGIN [%] is 20.
        QUANTITY is 1.
        TOTAL MASS NOMINAL [%] is 1.67.
        TOTAL MASS CONSERVATIVE [%] is 2.
    PMA is physical.
    PMA exhibits UNIT MASS NOMINAL [%], MARGIN [%], QUANTITY, TOTAL MASS NOMINAL [%], and TOTAL MASS CONSERVATIVE [%].
        UNIT MASS NOMINAL [%] is 0.83.
        MARGIN [%] is 20.
        QUANTITY is 1.
        TOTAL MASS NOMINAL [%] is 0.83.
        TOTAL MASS CONSERVATIVE [%] is 1.
    PPU is physical.
    PPU exhibits UNIT MASS NOMINAL [%], MARGIN [%], QUANTITY, TOTAL MASS NOMINAL [%], and TOTAL MASS CONSERVATIVE [%].
        UNIT MASS NOMINAL [%] is 2.5 .
        MARGIN [%] is 20.
        QUANTITY is 1.
        TOTAL MASS NOMINAL [%] is 2.5 .
        TOTAL MASS CONSERVATIVE [%] is 3.
ELECTRIC PROPULSION S/S zooms into TO PROVIDE NEEDED DELTA-V, TO CONTROL TU AND MANAGE PMA, TO PREVENT LOSS OF XENON, TO RUN THE THRUSTER AND SELECT THE CATHODE, TO CONTROL PMA TEMPERATURES, TO COPE WITH THE DEMANDE MASS FLOW RATE FOR THRUSTERS AND CATHODES, TO PROIVDE ISOLATION, and TO RPOTECT AGAINST CONTAMINATION.
    TO PROVIDE NEEDED DELTA-V is physical.
    TO PREVENT LOSS OF XENON is physical.
    TO RUN THE THRUSTER AND SELECT THE CATHODE is physical.
    TO PROIVDE ISOLATION is physical.
    TO RPOTECT AGAINST CONTAMINATION is physical.

Diagram 43: Electric propulsion S/S mass budget (OPL).



THERMO-STRUCTURE is physical.
THERMO-STRUCTURE exhibits TOTAL MASS NOMINAL [%] and TOTAL MASS CONSERVATIVE [%].
  TOTAL MASS NOMINAL [%] is 12.5.
  TOTAL MASS CONSERVATIVE [%] is 15.
THERMO-STRUCTURE consists of BM and TCS.
  BM is physical.
  BM exhibits UNIT MASS NOMINAL [%], MARGIN [%], QUANTITY, TOTAL MASS NOMINAL [%], and TOTAL MASS CONSERVATIVE [%].
    UNIT MASS NOMINAL [%] is 10.83.
    MARGIN [%] is 20.
    QUANTITY is 1.
    TOTAL MASS NOMINAL [%] is 10.83.
    TOTAL MASS CONSERVATIVE [%] is 13.
  TCS is physical.
  TCS exhibits UNIT MASS NOMINAL [%], MARGIN [%], QUANTITY, TOTAL MASS NOMINAL [%], and TOTAL MASS CONSERVATIVE [%].
    UNIT MASS NOMINAL [%] is 0.83.
    MARGIN [%] is 20.
    QUANTITY is 1.
    TOTAL MASS NOMINAL [%] is 0.83.
    TOTAL MASS CONSERVATIVE [%] is 1.

Diagram 44: Thermo-structure mass budget (OPD and OPL).

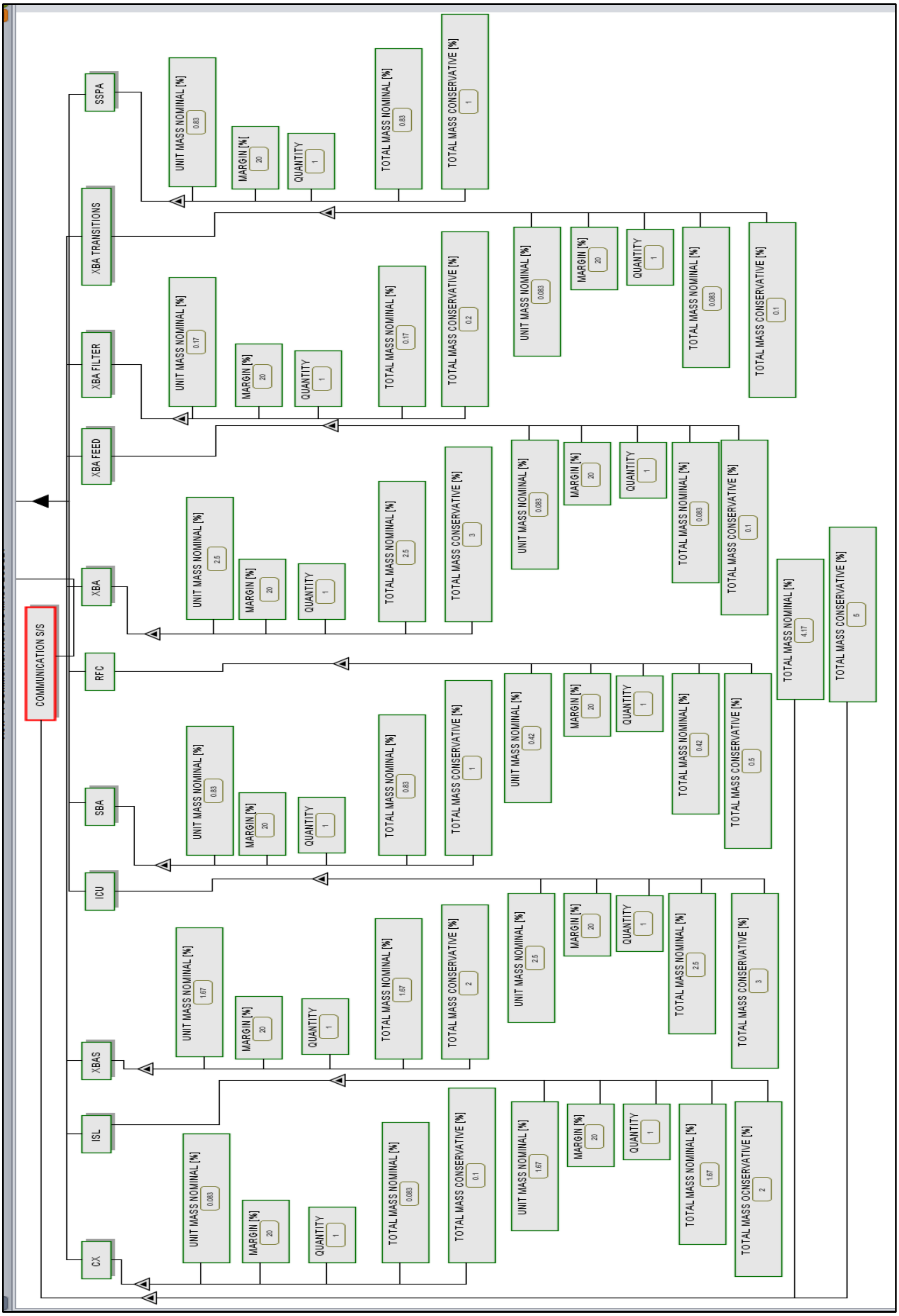


Diagram 45: Communication S/S mass budget (OPD).

COMMUNICATION S/S is physical.
COMMUNICATION S/S exhibits TOTAL MASS NOMINAL [%] and TOTAL MASS CONSERVATIVE [%].
TOTAL MASS NOMINAL [%] is 4.17.
TOTAL MASS CONSERVATIVE [%] is 5.
COMMUNICATION S/S consists of ICU, SBA, RFC, CX, XBA, SSPA, XBA FILTER, XBA FEED, XBA TRANSITIONS, XBAS, and ISL.
ICU is physical.
ICU exhibits UNIT MASS NOMINAL [%], MARGIN [%], QUANTITY, TOTAL MASS NOMINAL [%], and TOTAL MASS CONSERVATIVE [%].
UNIT MASS NOMINAL [%] is 2.5.
MARGIN [%] is 20.
QUANTITY is 1.
TOTAL MASS NOMINAL [%] is 2.5.
TOTAL MASS CONSERVATIVE [%] is 3.
SBA is physical.
SBA exhibits UNIT MASS NOMINAL [%], MARGIN [%], QUANTITY, TOTAL MASS NOMINAL [%], and TOTAL MASS CONSERVATIVE [%].
UNIT MASS NOMINAL [%] is 0.83.
MARGIN [%] is 20.
QUANTITY is 1.
TOTAL MASS NOMINAL [%] is 0.83.
TOTAL MASS CONSERVATIVE [%] is 1.
RFC exhibits UNIT MASS NOMINAL [%], MARGIN [%], QUANTITY, TOTAL MASS NOMINAL [%], and TOTAL MASS CONSERVATIVE [%].
UNIT MASS NOMINAL [%] is 0.42.
MARGIN [%] is 20.
QUANTITY is 1.
TOTAL MASS NOMINAL [%] is 0.42.
TOTAL MASS CONSERVATIVE [%] is 0.5.
CX is physical.
CX exhibits UNIT MASS NOMINAL [%], MARGIN [%], QUANTITY, TOTAL MASS NOMINAL [%], and TOTAL MASS CONSERVATIVE [%].
UNIT MASS NOMINAL [%] is 0.083.
MARGIN [%] is 20.
QUANTITY is 1.
TOTAL MASS NOMINAL [%] is 0.083.
TOTAL MASS CONSERVATIVE [%] is 0.1.
XBA is physical.
XBA exhibits UNIT MASS NOMINAL [%], MARGIN [%], QUANTITY, TOTAL MASS NOMINAL [%], and TOTAL MASS CONSERVATIVE [%].
UNIT MASS NOMINAL [%] is 2.5.
MARGIN [%] is 20.
QUANTITY is 1.
TOTAL MASS NOMINAL [%] is 2.5.
TOTAL MASS CONSERVATIVE [%] is 3.
SSPA is physical.
SSPA exhibits UNIT MASS NOMINAL [%], MARGIN [%[, QUANTITY, TOTAL MASS NOMINAL [%], and TOTAL MASS CONSERVATIVE [%].
UNIT MASS NOMINAL [%] is 0.83.
MARGIN [%[is 20.
QUANTITY is 1.
TOTAL MASS NOMINAL [%] is 0.83.
TOTAL MASS CONSERVATIVE [%] is 1.
XBA FILTER is physical.
XBA FILTER exhibits UNIT MASS NOMINAL [%], MARGIN [%], QUANTITY, TOTAL MASS NOMINAL [%], and TOTAL MASS CONSERVATIVE [%].
UNIT MASS NOMINAL [%] is 0.17.
MARGIN [%] is 20.
QUANTITY is 1.

TOTAL MASS NOMINAL [%] is 0.17.
TOTAL MASS CONSERVATIVE [%] is 0.2.
XBA FEED is physical.
XBA FEED exhibits UNIT MASS NOMINAL [%], MARGIN [%], QUANTITY, TOTAL MASS NOMINAL [%], and TOTAL MASS CONSERVATIVE [%].
UNIT MASS NOMINAL [%] is 0.083.
MARGIN [%] is 20.
QUANTITY is 1.
TOTAL MASS NOMINAL [%] is 0.083.
TOTAL MASS CONSERVATIVE [%] is 0.1.
XBA TRANSITIONS is physical.
XBA TRANSITIONS exhibits UNIT MASS NOMINAL [%], MARGIN [%], QUANTITY, TOTAL MASS NOMINAL [%], and TOTAL MASS CONSERVATIVE [%].
UNIT MASS NOMINAL [%] is 0.083.
MARGIN [%] is 20.
QUANTITY is 1.
TOTAL MASS NOMINAL [%] is 0.083.
TOTAL MASS CONSERVATIVE [%] is 0.1.
XBAS is physical.
XBAS exhibits UNIT MASS NOMINAL [%], MARGIN [%], QUANTITY, TOTAL MASS NOMINAL [%], and TOTAL MASS CONSERVATIVE [%].
UNIT MASS NOMINAL [%] is 1.67.
MARGIN [%] is 20.
QUANTITY is 1.
TOTAL MASS NOMINAL [%] is 1.67.
TOTAL MASS CONSERVATIVE [%] is 2.
ISL is physical.
ISL exhibits UNIT MASS NOMINAL [%], MARGIN [%], QUANTITY, TOTAL MASS NOMINAL [%], and TOTAL MASS OCNSERVATIVE [%].
UNIT MASS NOMINAL [%] is 1.67.
MARGIN [%] is 20.
QUANTITY is 1.
TOTAL MASS NOMINAL [%] is 1.67.
TOTAL MASS OCNSERVATIVE [%] is 2.

COMMUNICATION S/S zooms into PAYLOAD DATA HANDLING AND TRANSMISSION, TELEMETRY, TRACKING AND CONTROL, FORMATTING DIFFREENT DATA FLUXE, ACQUIRING PAYLOAD, AUXILIARY DATA AND S/C TM, MODULATING, RECEIVING AND PROVIDING DISCRETE AND SERIAL TM AND TC, and FILTERING TRANSMISSION SIGNALS.

PAYLOAD DATA HANDLING AND TRANSMISSION is physical.

TELEMETRY, TRACKING AND CONTROL is physical.

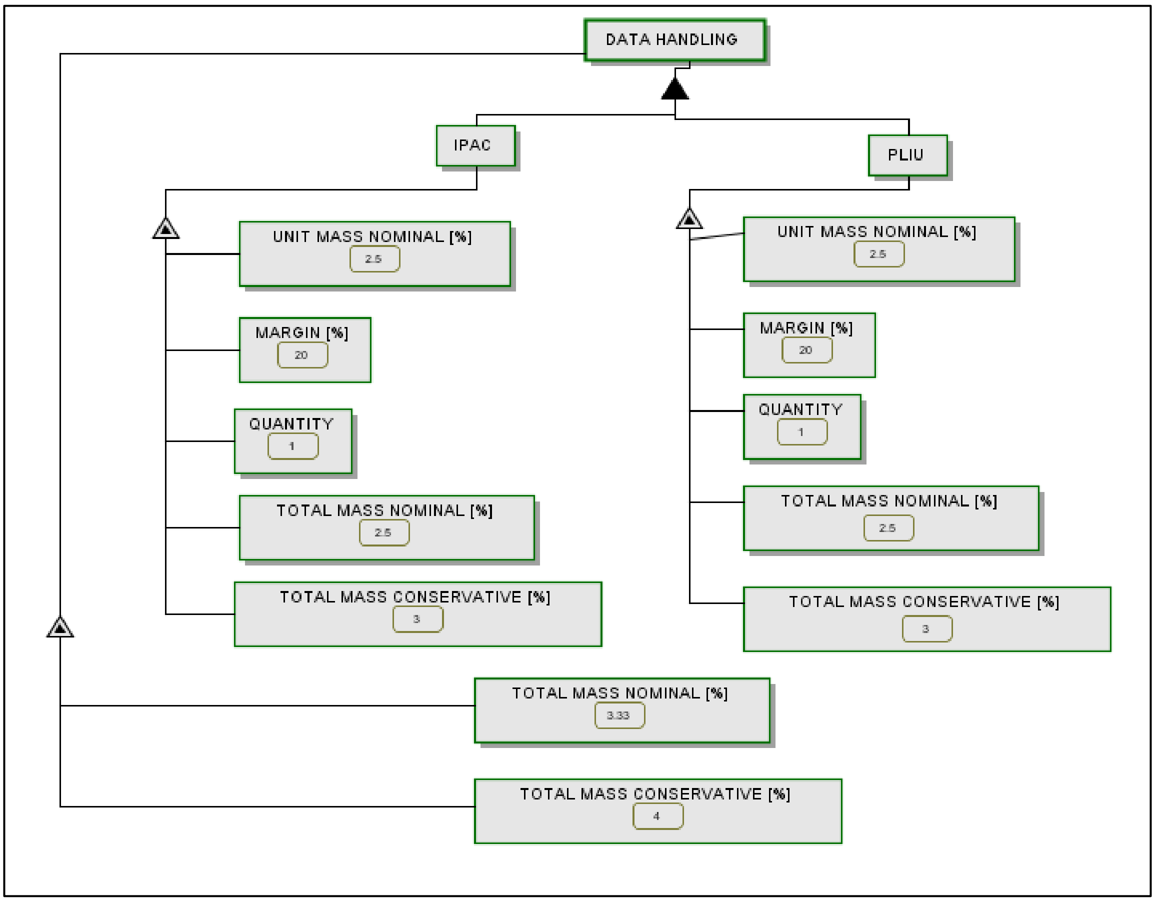
FORMATTING DIFFREENT DATA FLUXE is physical.

MODULATING is physical.

RECEIVING AND PROVIDING DISCRETE AND SERIAL TM AND TC is physical.

FILTERING TRANSMISSION SIGNALS is physical.

Diagram 46: Communication S/S mass budget (OPL).



DATA HANDLING is physical.
DATA HANDLING exhibits TOTAL MASS NOMINAL [%] and TOTAL MASS CONSERVATIVE [%].
    TOTAL MASS NOMINAL [%] is physical.
    TOTAL MASS NOMINAL [%] is 3.33.
    TOTAL MASS CONSERVATIVE [%] is 4.
DATA HANDLING consists of IPAC and PLIU.
    IPAC is physical.
    IPAC exhibits UNIT MASS NOMINAL [%], MARGIN [%], QUANTITY, TOTAL MASS NOMINAL [%], and TOTAL MASS CONSERVATIVE [%].
        UNIT MASS NOMINAL [%] is physical.
        UNIT MASS NOMINAL [%] is 2.5.
        MARGIN [%] is 20.
        QUANTITY is physical.
        QUANTITY is 1.
        TOTAL MASS NOMINAL [%] is physical.
        TOTAL MASS NOMINAL [%] is 2.5.
        TOTAL MASS CONSERVATIVE [%] is 3.
    PLIU is physical.
    PLIU exhibits UNIT MASS NOMINAL [%], MARGIN [%], QUANTITY, TOTAL MASS NOMINAL [%], and TOTAL MASS CONSERVATIVE [%].
        UNIT MASS NOMINAL [%] is physical.
        UNIT MASS NOMINAL [%] is 2.5.
        MARGIN [%] is 20.
        QUANTITY is physical.
        QUANTITY is 1.
        TOTAL MASS NOMINAL [%] is physical.
        TOTAL MASS NOMINAL [%] is 2.5.
        TOTAL MASS CONSERVATIVE [%] is 3.

Diagram 47: Data handling mass budget (OPD and OPL).

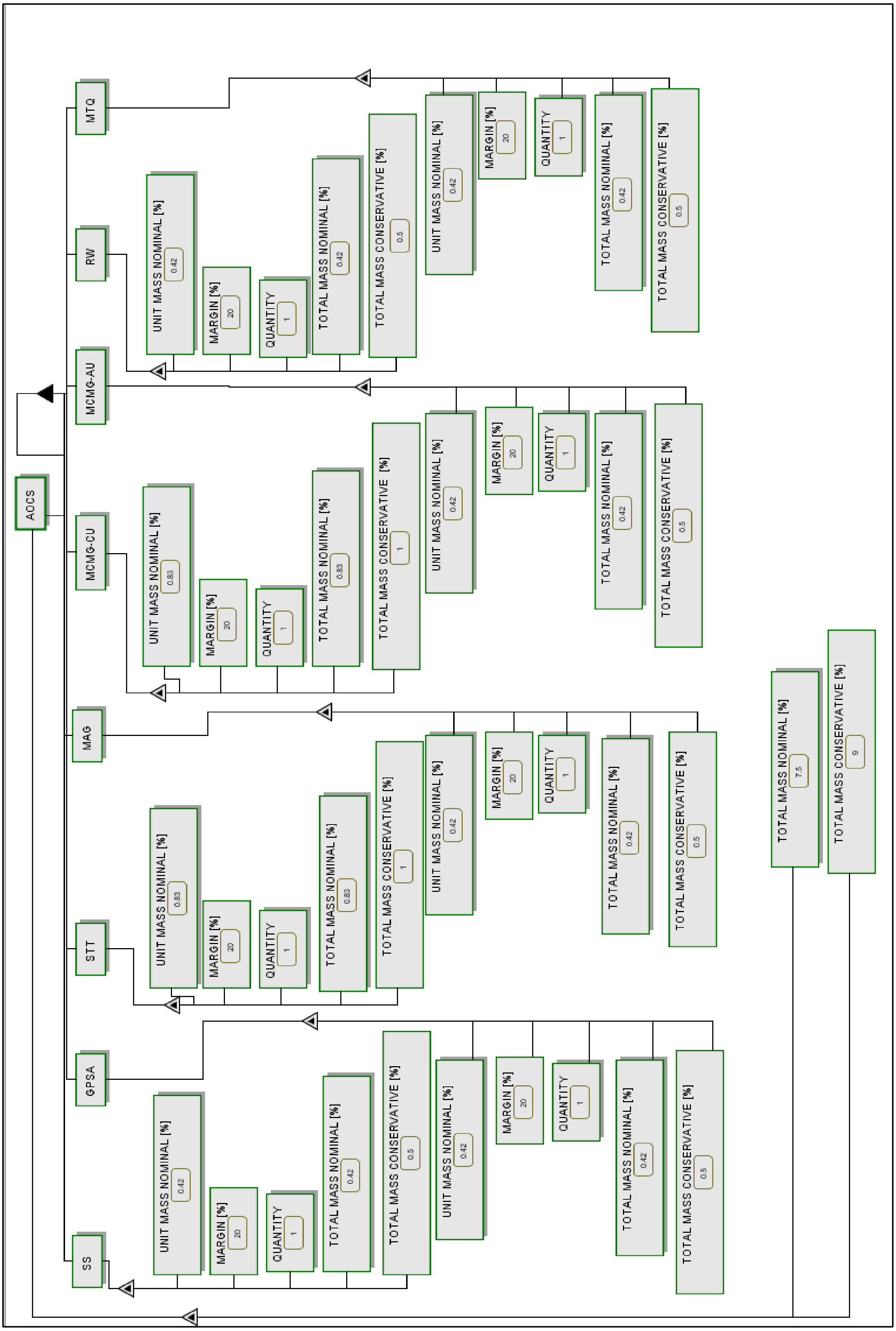


Diagram 48: AOCS mass budget (OPD).

AOCS is physical.
AOCS exhibits TOTAL MASS NOMINAL [%] and TOTAL MASS CONSERVATIVE [%].
    TOTAL MASS NOMINAL [%] is physical.
    TOTAL MASS NOMINAL [%] is 7.5.
    TOTAL MASS CONSERVATIVE [%] is 9.
AOCS consists of STT, MAG, SS, GPSA, MTQ, RW, MCMG-AU, and MCMG-CU.
    STT is physical.
    STT exhibits UNIT MASS NOMINAL [%], MARGIN [%], QUANTITY, TOTAL MASS NOMINAL [%], and TOTAL MASS CONSERVATIVE [%].
        UNIT MASS NOMINAL [%] is physical.
        UNIT MASS NOMINAL [%] is 0.83.
        MARGIN [%] is 20.
        QUANTITY is physical.
        QUANTITY is 1.
        TOTAL MASS NOMINAL [%] is physical.
        TOTAL MASS NOMINAL [%] is 0.83.
        TOTAL MASS CONSERVATIVE [%] is 1.
    MAG is physical.
    MAG exhibits UNIT MASS NOMINAL [%], MARGIN [%], QUANTITY, TOTAL MASS NOMINAL [%], and TOTAL MASS CONSERVATIVE [%].
        UNIT MASS NOMINAL [%] is physical.
        UNIT MASS NOMINAL [%] is 0.42.
        MARGIN [%] is 20.
        QUANTITY is physical.
        QUANTITY is 1.
        TOTAL MASS NOMINAL [%] is physical.
        TOTAL MASS NOMINAL [%] is 0.42.
        TOTAL MASS CONSERVATIVE [%] is 0.5.
    SS is physical.
    SS exhibits UNIT MASS NOMINAL [%], MARGIN [%], QUANTITY, TOTAL MASS NOMINAL [%], and TOTAL MASS CONSERVATIVE [%].
        UNIT MASS NOMINAL [%] is physical.
        UNIT MASS NOMINAL [%] is 0.42.
        MARGIN [%] is 20.
        QUANTITY is physical.
        QUANTITY is 1.
        TOTAL MASS NOMINAL [%] is physical.
        TOTAL MASS NOMINAL [%] is 0.42.
        TOTAL MASS CONSERVATIVE [%] is 0.5.
    GPSA is physical.
    GPSA exhibits UNIT MASS NOMINAL [%], MARGIN [%], QUANTITY, TOTAL MASS NOMINAL [%], and TOTAL MASS CONSERVATIVE [%].
        UNIT MASS NOMINAL [%] is physical.
        UNIT MASS NOMINAL [%] is 0.42.
        MARGIN [%] is 20.
        QUANTITY is physical.
        QUANTITY is 1.
        TOTAL MASS NOMINAL [%] is physical.
        TOTAL MASS NOMINAL [%] is 0.42.
        TOTAL MASS CONSERVATIVE [%] is 0.5.

    MTQ is physical.
    MTQ exhibits UNIT MASS NOMINAL [%], MARGIN [%], QUANTITY, TOTAL MASS NOMINAL [%], and TOTAL MASS CONSERVATIVE [%].
        UNIT MASS NOMINAL [%] is physical.
        UNIT MASS NOMINAL [%] is 0.42.
        MARGIN [%] is 20.
        QUANTITY is physical.
        QUANTITY is 1.
        TOTAL MASS NOMINAL [%] is physical.
        TOTAL MASS NOMINAL [%] is 0.42.
        TOTAL MASS CONSERVATIVE [%] is 0.5.
    RW is physical.
    RW exhibits UNIT MASS NOMINAL [%], MARGIN [%], QUANTITY, TOTAL MASS NOMINAL [%], and TOTAL MASS CONSERVATIVE [%].
        UNIT MASS NOMINAL [%] is physical.
        UNIT MASS NOMINAL [%] is 0.42.
        MARGIN [%] is 20.
        QUANTITY is physical.
        QUANTITY is 1.
        TOTAL MASS NOMINAL [%] is physical.
        TOTAL MASS NOMINAL [%] is 0.42.
        TOTAL MASS CONSERVATIVE [%] is 0.5.
    MCMG-AU is physical.
    MCMG-AU exhibits UNIT MASS NOMINAL [%], MARGIN [%], QUANTITY, TOTAL MASS NOMINAL [%], and TOTAL MASS CONSERVATIVE [%].
        UNIT MASS NOMINAL [%] is physical.
        UNIT MASS NOMINAL [%] is 0.42.
        MARGIN [%] is 20.
        QUANTITY is physical.
        QUANTITY is 1.
        TOTAL MASS NOMINAL [%] is physical.
        TOTAL MASS NOMINAL [%] is 0.42.
        TOTAL MASS CONSERVATIVE [%] is 0.5.
    MCMG-CU is physical.
    MCMG-CU exhibits UNIT MASS NOMINAL [%], MARGIN [%], QUANTITY, TOTAL MASS NOMINAL [%], and TOTAL MASS CONSERVATIVE [%].
        UNIT MASS NOMINAL [%] is physical.
        UNIT MASS NOMINAL [%] is 0.83.
        MARGIN [%] is 20.
        QUANTITY is physical.
        QUANTITY is 1.
        TOTAL MASS NOMINAL [%] is physical.
        TOTAL MASS NOMINAL [%] is 0.83.
        TOTAL MASS CONSERVATIVE [%] is 1.

Diagram 49: AOCS mass budget (OPL).

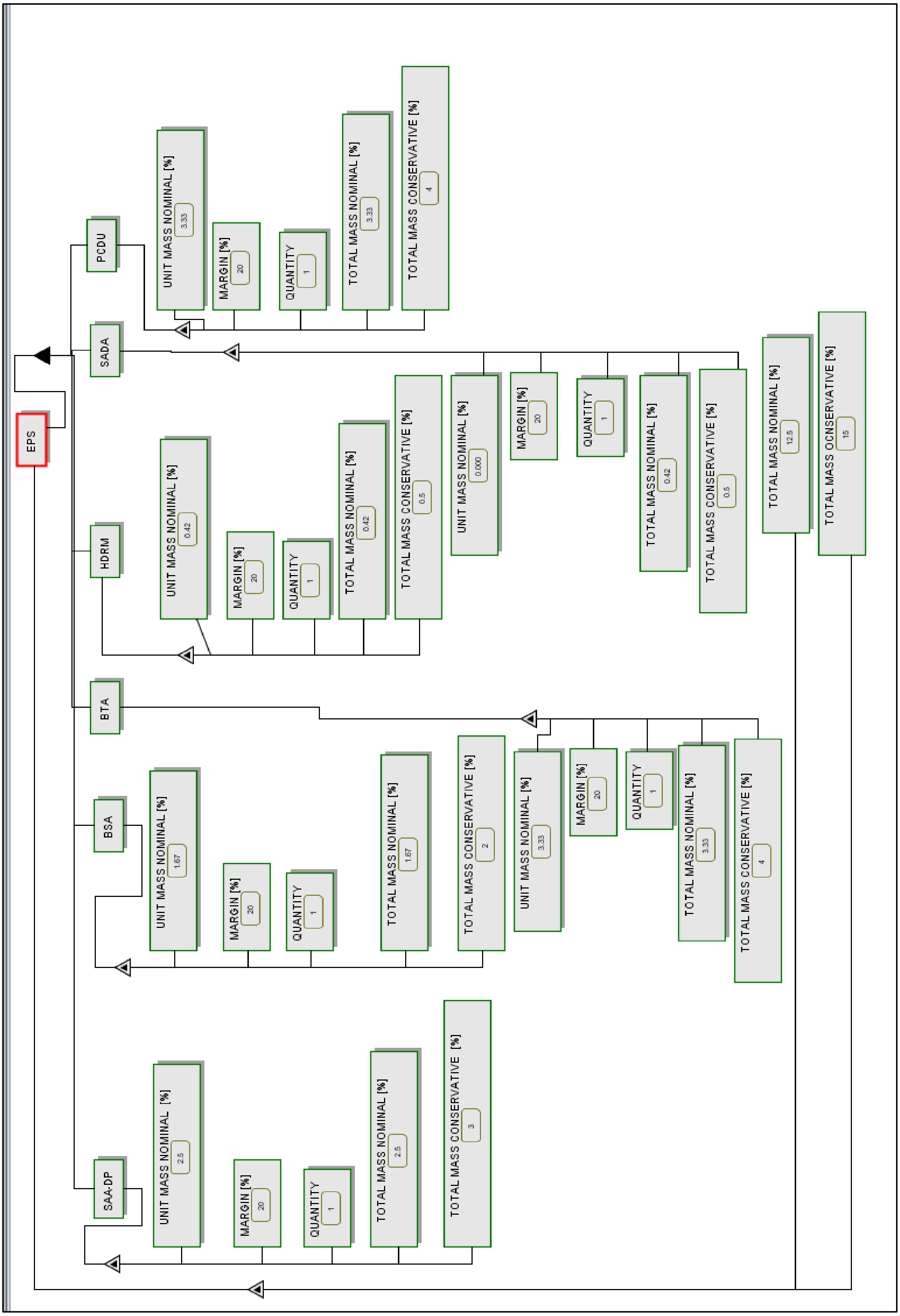


Diagram 50: EPS mass budget (OPD).

```
EPS is physical.
EPS exhibits TOTAL MASS NOMINAL [%] and TOTAL MASS OCNSERVATIVE [%].
    TOTAL MASS NOMINAL [%] is physical.
    TOTAL MASS NOMINAL [%] is 12.5.
    TOTAL MASS OCNSERVATIVE [%] is 15.
EPS consists of PCDU, BTA, HDRM, SADA, SAA-DP, and BSA.
    PCDU is physical.
    PCDU exhibits UNIT MASS NOMINAL [%], MARGIN [%], QUANTITY, TOTAL MASS NOMINAL [%], and TOTAL MASS CONSERVATIVE [%].
        UNIT MASS NOMINAL [%] is physical.
        UNIT MASS NOMINAL [%] is 3.33.
        MARGIN [%] is 20.
        QUANTITY is physical.
        QUANTITY is 1.
        TOTAL MASS NOMINAL [%] is physical.
        TOTAL MASS NOMINAL [%] is 3.33.
        TOTAL MASS CONSERVATIVE [%] is 4.
    BTA is physical.
    BTA exhibits UNIT MASS NOMINAL [%], MARGIN [%], QUANTITY, TOTAL MASS NOMINAL [%], and TOTAL MASS CONSERVATIVE [%].
        UNIT MASS NOMINAL [%] is physical.
        UNIT MASS NOMINAL [%] is 3.33.
        MARGIN [%] is 20.
        QUANTITY is physical.
        QUANTITY is 1.
        TOTAL MASS NOMINAL [%] is physical.
        TOTAL MASS NOMINAL [%] is 3.33.
        TOTAL MASS CONSERVATIVE [%] is 4.
    HDRM is physical.
    HDRM exhibits UNIT MASS NOMINAL [%], MARGIN [%], QUANTITY, TOTAL MASS NOMINAL [%], and TOTAL MASS CONSERVATIVE [%].
        UNIT MASS NOMINAL [%] is physical.
        UNIT MASS NOMINAL [%] is 0.42.
        MARGIN [%] is 20.
        QUANTITY is physical.
        QUANTITY is 1.
        TOTAL MASS NOMINAL [%] is physical.
        TOTAL MASS NOMINAL [%] is 0.42.
        TOTAL MASS CONSERVATIVE [%] is 0.5.
    SADA is physical.
    SADA exhibits UNIT MASS NOMINAL [%], MARGIN [%], QUANTITY, TOTAL MASS NOMINAL [%], and TOTAL MASS CONSERVATIVE [%].
        UNIT MASS NOMINAL [%] is physical.
        UNIT MASS NOMINAL [%] is 0.000.
        MARGIN [%] is 20.
        QUANTITY is physical.
        QUANTITY is 1.
        TOTAL MASS NOMINAL [%] is physical.
        TOTAL MASS NOMINAL [%] is 0.42.
        TOTAL MASS CONSERVATIVE [%] is 0.5.
```

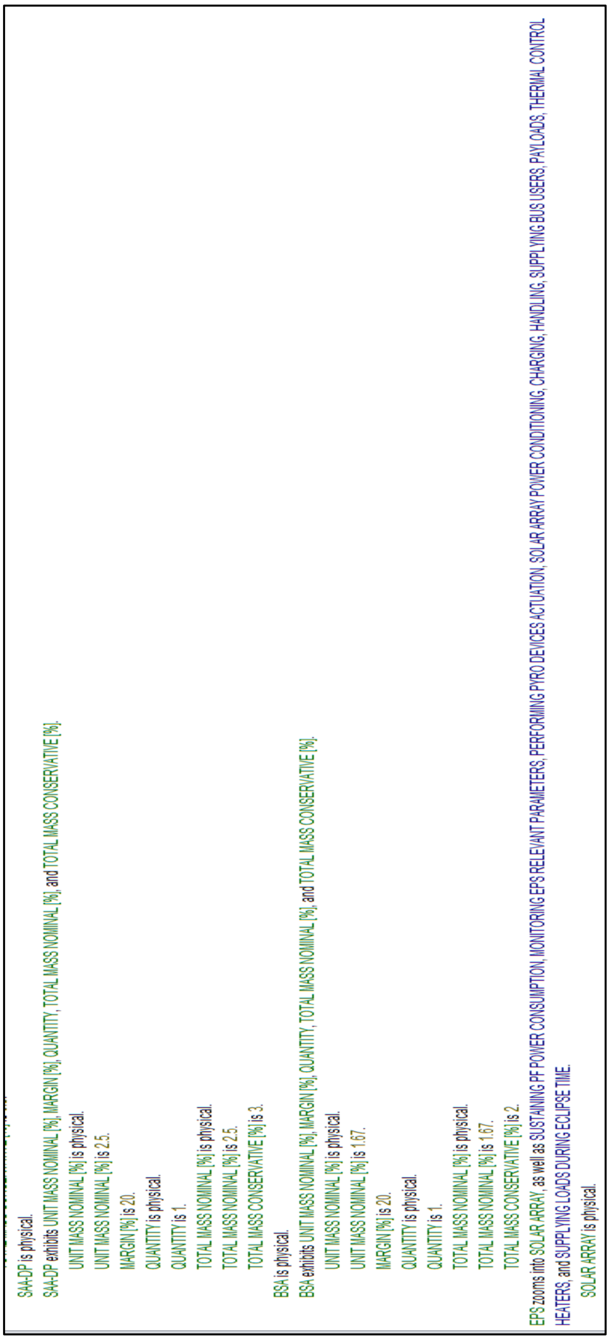


Diagram 51: EPS mass budget (OPL).

With the resulting mass budget of the subsystems, it has been created a view with the platform mass budget. This view has been created in order to have a global vision on two levels: that of the platform and that of its subsystems, hiding the third level, that is the subsystems' units. In this way it is evident what subsystem affects more the global platform mass.

4.3.10 PLATiNO Platform global mass budget

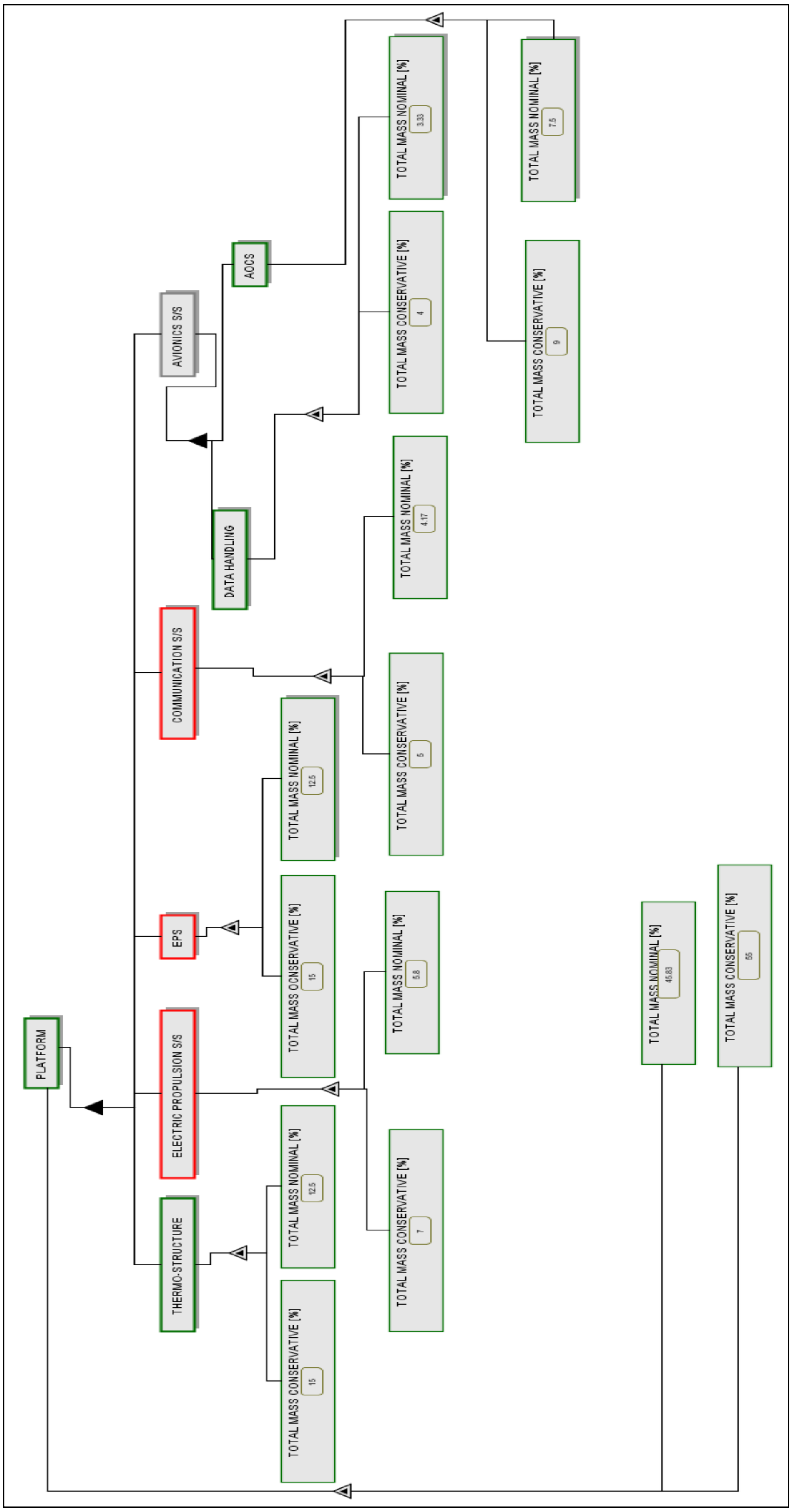


Diagram 52: Platform mass budget (OPD).

PLATFORM is physical.
PLATFORM exhibits TOTAL MASS NOMINAL [%] and TOTAL MASS CONSERVATIVE [%].
TOTAL MASS NOMINAL [%] is 45.83.
TOTAL MASS CONSERVATIVE [%] is 55.
PLATFORM consists of THERMO-STRUCTURE, EPS, COMMUNICATION S/S, AVIONICS S/S, and ELECTRIC PROPULSION S/S.
THERMO-STRUCTURE is physical.
THERMO-STRUCTURE exhibits TOTAL MASS NOMINAL [%] and TOTAL MASS CONSERVATIVE [%].
TOTAL MASS NOMINAL [%] is 12.5.
TOTAL MASS CONSERVATIVE [%] is 15.
EPS is physical.
EPS exhibits TOTAL MASS NOMINAL [%] and TOTAL MASS OCNSERVATIVE [%].
TOTAL MASS NOMINAL [%] is physical.
TOTAL MASS NOMINAL [%] is 12.5.
TOTAL MASS OCNSERVATIVE [%] is 15.
COMMUNICATION S/S is physical.
COMMUNICATION S/S exhibits TOTAL MASS NOMINAL [%] and TOTAL MASS CONSERVATIVE [%].
TOTAL MASS NOMINAL [%] is 4.17.
TOTAL MASS CONSERVATIVE [%] is 5.
AVIONICS S/S is physical.
AVIONICS S/S consists of AOCS and DATA HANDLING.
AOCS is physical.
AOCS exhibits TOTAL MASS NOMINAL [%] and TOTAL MASS CONSERVATIVE [%].
TOTAL MASS NOMINAL [%] is physical.
TOTAL MASS NOMINAL [%] is 7.5.
TOTAL MASS CONSERVATIVE [%] is 9.
DATA HANDLING is physical.
DATA HANDLING exhibits TOTAL MASS NOMINAL [%] and TOTAL MASS CONSERVATIVE [%].
TOTAL MASS NOMINAL [%] is physical.
TOTAL MASS NOMINAL [%] is 3.33.
TOTAL MASS CONSERVATIVE [%] is 4.
ELECTRIC PROPULSION S/S is physical.
ELECTRIC PROPULSION S/S exhibits TOTAL MASS NOMINAL [%] and TOTAL MASS CONSERVATIVE [%].
TOTAL MASS NOMINAL [%] is 5.8.
TOTAL MASS CONSERVATIVE [%] is 7.

Diagram 53: Platform mass budget (OPL).

5. DISCUSSION OF THE RESULTS

The current “modus operandi” in Italian industries concerns the traditional documental Systems engineering approach. For example, the product tree (that is the “platform architecture” in the above diagrams) and the mass budget are drawn up on different documents and by different people. In particular, the first one is a graphical representation in which only the name of the components appear (without any technical information); it is a task of the “management sector responsible”. The latter is an excel worksheet drawn up by “System Sector responsible”. With the diagrams realized in OPCAT environment, these two SE products are contained in the same file and obtained with the same tool. In fact, the “platform architecture” corresponds to the product tree. Starting from this diagram and proceeding by unfolding in each square, it is possible to obtain the mass budget of each subsystem (taking into account all the units which compose it) and which of the platform. So, by this way, it is obtained a centralization of the information and a better performed management of them. It makes easier and faster the communication among team members, and this affects the reduction of the time to market.

Moreover, the graphical description of the system gives the chance to proceed in a more structured way towards the system requirements definition: from the start of the project, one wonders what composes the system, what system should do, its states and interfaces into it and build OPCAT diagrams. Starting from this, it is possible to derive, in a rational way, all the requirements which will act as drivers into the development of the design.

In particular, from diagrams which represents the functional analysis of subsystems, functional requirements can be obtained. From the states/modes diagrams, interface requirements can be derived. Whereas, physical requirements can be obtained from the “architecture diagrams”. By this way, it is possible to have a global picture of the system from the start of the design and moving on to the consequent levels of decomposition.

Moreover, the development of the design is an iterative process, so any changes in a document will constitute the updated version of it and it is possible that some team members use the old one, making mistakes. But having a single file on which to make changes, will avoid this type of errors.

Diagrams obtained are not all those needed in order to describe the system as a whole, but they are some possible applications of OPM to PLATiNO satellite focusing on its structure, its behaviour and its function. In fact, structure, behaviour and function are the three aspects of the system that OPM aims to describe in a single type of diagram. In particular, the structure of PLATiNO 1 can be observed into the “satellite architecture”, “platform architecture”, “PLATiNO 1 configuration” diagrams,; but also the mass budget diagrams are intended as characteristics of the structure of the system; the behaviour is contained in the “mission phases”, “operative phases” diagrams; whereas the functions are made explicit into the diagrams which have been obtained by in-zoom from the “platform architecture” diagram.

These aspects of the description of the system can also be found in a SySML approach, but they would appear divided into several types of diagrams. In fact, a correspondence can be found between the two approaches in terms of diagrams which describe PLATiNO 1 satellite. In particular, for example, in SySML the behaviour of the examined system could be expressed through two types of diagram: the State Machine Diagram, which correspond to the “LEOP in-zoomed” and “mission phase in-zoom” diagrams realized in OPCAT; the Activity Diagram which might correspond to the OPCAT diagrams, in which subsystems’ functions are represented. The structural aspect of the system in SySML is contained into the Block Definition Diagram, which might be associated to the OPCAT “platform architecture” and “satellite architecture” diagrams, and the Internal Block Diagram which might correspond to the OPCAT “PLATiNO 1 configurations” or “operative phases characterization” diagrams. A prerogative of SySML respect to UML is the Parametric Diagram which might be associated to the OPCAT mass budget diagrams. It is significant to observe that in these lines five types of diagram, each with a different construction, are listed. The same aspects of PLATiNO 1 satellite have been described with OPM in OPCAT environment using a single type of diagram.

In fact, OPCAT has been a great helper in the application of OPM to PLATiNO. Thanks to it, the three-dimensional vision of the system development was constantly visible: in fact, the in-zoom paths are highlighted by a more evident left margin respect to that of the upper level as shown in the following picture.

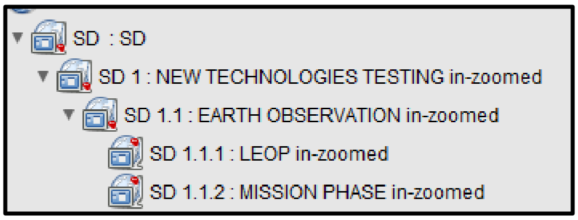


Figure 15: Example of OPCAT display of system levels.

Moreover, the OPM equivalent sentence automatically appears under the workspace in which an OPM element has been placed. This allowed to verify if the built OPM relation was in compliance with what we would express. Another interesting OPCAT feature was the change of the thickness of the contour line if an element was unfolded or in-zoomed:

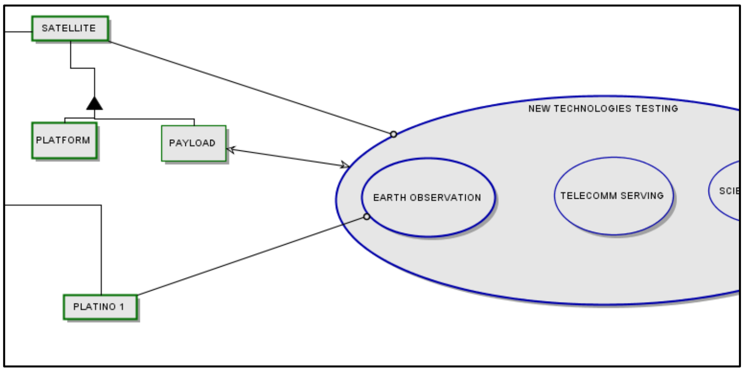


Figure 16: Example of OPCAT in-zoomed entities' boundary line thicketing.

At a glance, the elements specified at other levels of decomposition capture one attention.

The colour of elements even changes when an object which has been specified with some notes is hovered over and it was helpful to simplify diagrams inserting acronyms instead of entire words:

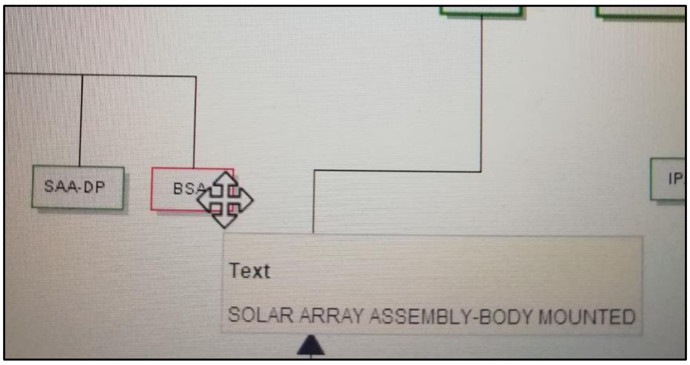


Figure 17: Example of OPCAT possibility to clarify acronyms.

As previous anticipated, OPCAT does not allow relations which are in contrast with OPM principles:

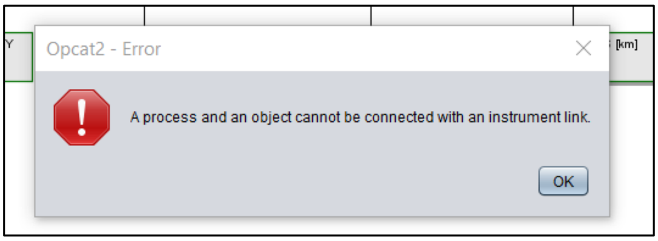


Figure 18: Example of OPCAT error message.

Moreover, when an in-zoom or an unfold diagram is created, the element in-zoomed or unfolded appears in a new diagram maintaining all the main relations, so I do not have to put them in manually.

OPCAT tool facilitates the work and avoid conceptual errors which might be really significant in a multi-domain context characterized by several companies involved.

In conclusion, downstream of the analysis, it can be deduced that OPM approach works well in the phases 0/A of the project life cycle, but it begins to show its weaknesses already in the phase B. This deduction confirms what reported in the paper titled "*System Modeling Language Languages: OPM Versus SySML*" [14] in which it is written that "SySML tends to be more appropriates in cases where a detailed picture is required. Alternatively, OPM is more suitable for defining system boundaries and demonstrating the overall picture of the system". In fact, with the obtained diagrams it is possible to identify design development drivers and system concepts, elaborate possible design architectures, establish a clear functional and technical requirements baseline. Phase B requires the establishment of a preliminary design definition for the selected system concept and retained technical solution. So, the level of detail needed by this phase might be implemented using the OPM ontology, but diagrams would assume a shape such that it would not be so comprehensible. This is in part already evident in diagrams which represent the functional analysis of the subsystems: next example shows an intertwining of lines that is not so clear to be quickly decoded.

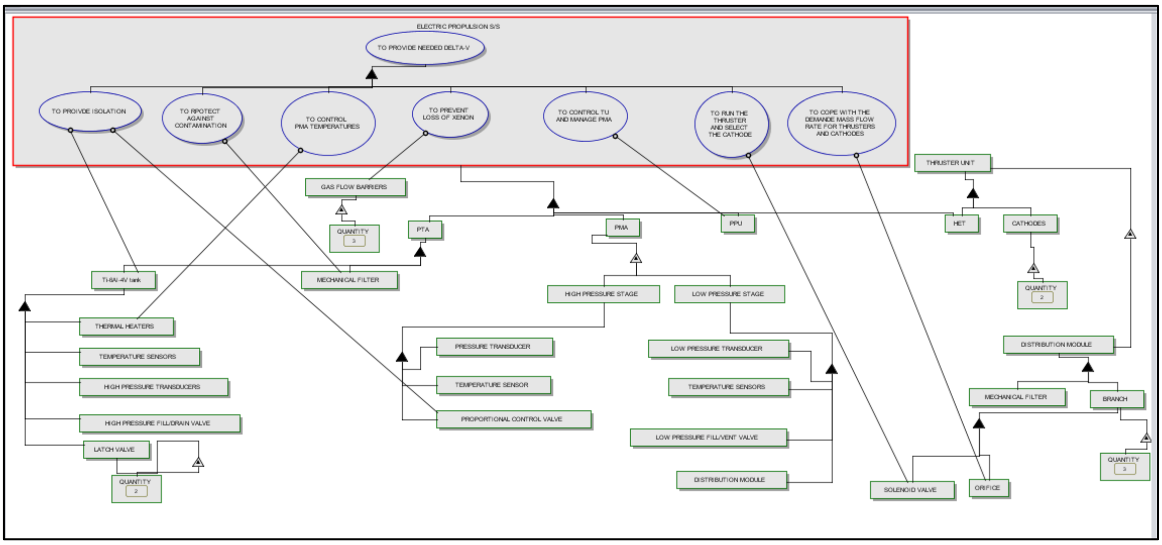


Figure 19: Example of an OPCAT unclear diagram.

However, diagrams obtained might be part of a SRR in response to one of the objectives of this document, that is the release of updated technical requirements specification.

Accordingly, OPM approach improves the global visualization of the system, allowing an unambiguous communication among team members, makes more efficient the requirements SE activity and establishes a clear path for the consequent steps of the development of the design, such as trade-off studies. For these reasons, the quality of the design turns out to be improved because time is saved, and a lot of potential errors are detected or avoided.

6. FINAL CONSIDERATIONS AND A LOOK FORWARD

Downstream of the analysis, it can be observed that the validity of the use of OPM becomes more evident when it comes to the development of a completely new product for the company. In fact, as in the case of PLATiNO 1, if the company does not have any heritage of information about the product, it must be developed in each of its part from the beginning of the project. When a product has the same basic features as an existing one, team members can work on the trail of data already present in the company database and proceed in a direction already travelled previously, with the changes required by the case. If it is not possible, it makes sense to use OPM in order to centralize information and move the team in a clear and entirely new direction from the very beginning of the project.

Accordingly, the choice of implementing OPM diagrams to this case study has confirmed the points in favour of its employment listed in 3.2 paragraph, "SySML VERSUS OPM", because it has given satisfying results in terms of efficiency, ease of use, ease of communication, building basis for consequent development design phases.

This innovative approach allows to easily make changes to the design of the system, at the same time verifying that there are no conflicts that are difficult to identify with traditional methods. The added value of the work can be explicated in several points:

- It improves the communication among the several companies involved with SITAEL in the project.
- The specification tree might be translated into a visual, more direct diagram.
- The trade-off activity might be accelerated and simplified due to the visual description of the hypothetical system solution.
- Succeeding in linking satellite states with mission phases or subsystems' modes, can be helpful in making budgets and implementing controls during the product development.
- The displayed diagrams, reunited in a single conceptual model, can replace the numerous matrices and excel worksheets of the SE activities. In particular, this work focused on the improvement of the efficiency of the SE activities of "Engineering Requirements" and, to a lesser extent, of the "Design and Configuration".

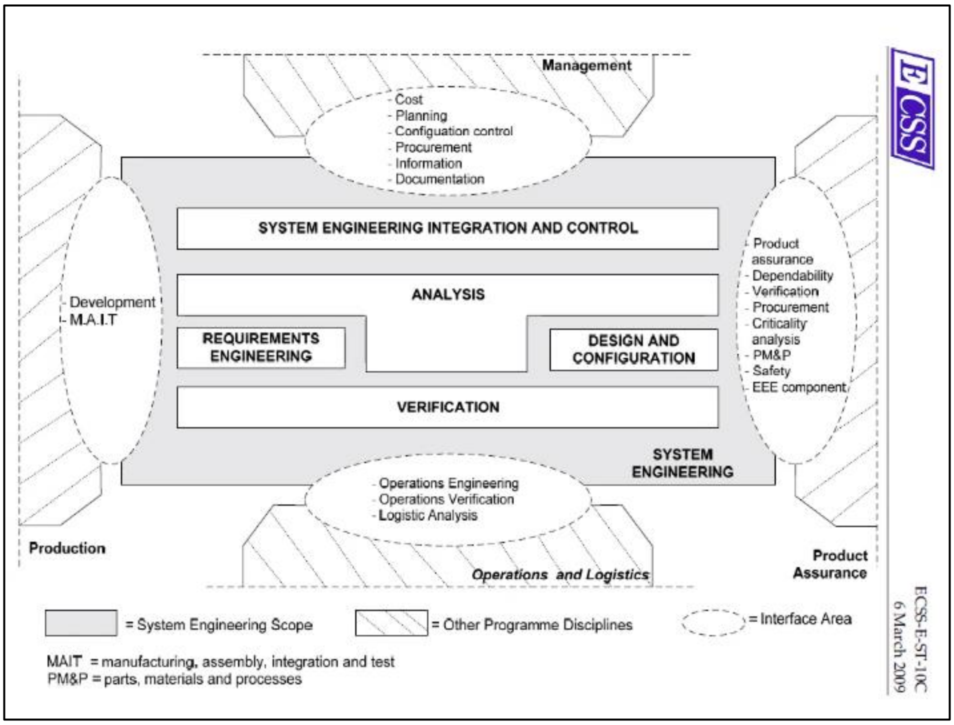


Figure 20: ECSS systems engineering functions and boundaries [25].

Despite the several possible advantages, the analysis revealed also the weaknesses of the application of OPM. In fact, as previously discussed, at high levels it works very well but, proceeding to lower ones, it is difficult to make comprehensible the suitable relations between elements with OPM entities. In fact, even the type of transforming link called “effect link” is not so accurate in its meaning: it expresses that in general the object is changed by the process, but it is not specified “how” it is affected in detail.

For this reason, it seems that, at the moment, the complete replacement of the documents cannot be realized with OPM approach. It is more plausible that the amount of documents is reduced and supported by the conceptual models.

However, the direction to my work is addressed is that, traced by ESA, concerning the realization of the “digital twin” of the system. In fact, along the historical period we are living in, defined as “Space 4.0 era”, “ESA needs to support industry with technology that helps to reduce production costs and increase production rates”. In this context, digital engineering, and therefore the digital conceptual model, represents the core of “Industry 4.0” and the “smart factory approach for faster product cycles” [26]. Space mission design and implementation are made more efficient by these new technologies. Their employment marks the transition from the traditional “design, build and then test” approach, which requires the intensive and expensive use of documentation, to the more agile “analyse and then build” approach. The latter implies the use of digital models to get digital test simulations which are part of the analysis.

In conclusion, some potential future implementations could be imagined:

- Translating the mass budgets in OPCAT workspace, it can be noticed that resulting total quantities must be inserted manually. It could be useful if some mathematical spreadsheets could be implemented in OPCAT environment, with the aim of improving the automatization.
- Probably, it might be useful to have the possibility of including some embedded text reading tools in OPCAT environment, such as word, Excel, PDF files, as additional supports entirely to the company.
- Trade off studies could be carried out in a practical way starting from OPM diagrams.
- Although the OPM approach has added value even if used only within the individual company, speeding up and facilitating teamwork, this would be even more valid if used by all the companies involved in PLATiNO 1 project, in order to centralize information at an even higher level.
- As the OPM approach proved to be very valid for the 0/A phases of the project, a hybrid PLATiNO 1 satellite model could be created. In particular, one could think of using OPM in the 0/A phases and SySML in the following ones.
- The whole model of PLATiNO 1 satellite could be built with another type of language, for example SySML, for comparison.
- The validity of OPM approach could be further explored by investigating its applicability to other types of SE activities, among those in Figure 20.
- OPM could be used in the conceptual description of other space systems, other than PLATiNO 1 satellite.

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RINGRAZIAMENTI

Dopo pagine di tecnicismi, sento l'inderogabile bisogno di permettere all'emozione di palesarsi nella sua totalità. Troppe volte ho pensato che questo tipo di studi non mi avrebbe mai permesso di esprimermi appieno. Mi sono sempre definita come una studentessa di ingegneria Anomala. Con gli anni ho capito che l'uomo è un sistema diverso da quelli che lui stesso crea: non può essere realizzato in serie. Chi lo ha detto che l'ingegnere deve possedere o non possedere, a tutti i costi, determinate caratteristiche? Io ho scelto di essere un ingegnere senza, però, lasciare che l'aridità di formule infinite o gli asettici meccanismi di funzionamento dei motori affievolissero la mia urgenza di sentimento.

Nella mia tesi, definendo il concetto di "sistema", rendo esplicito che il suo valore risiede nelle relazioni tra i suoi elementi.

Posso, dunque, ragionevolmente immaginare il sistema "Dott.ssa Miriam in Ingegneria Aerospaziale" come costituito dall'ostinata me, da tutte le persone che, da vicino o da lontano, hanno reso tangibile la loro presenza durante questo mio scabroso percorso, e dalle nostre interazioni a cui è da attribuire il carattere di unicità del sistema stesso.

L'obiettivo che giustifica l'esistenza del sistema è raggiungibile attraverso una particolare combinazione di interfacce tra sottosistemi che sono, a loro volta, dei sistemi anch'essi, dipendentemente dalla prospettiva da cui si sceglie di guardare.

Voglio, dunque, descrivere il Mio sistema dedicando queste dovute righe ai suoi imprescindibili componenti.

Grazie alla mia relatrice, prof.ssa Sabrina Corpino per avermi iniziata all'Ingegneria di sistema durante le sue lezioni. Mi ha, poi, supportata nella mia volontà di approfondire un così affascinante argomento in un'azienda che nasce nella mia terra, ma che guarda "verso l'infinito… e oltre!", come direbbe Buzz Lightyear.

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Oggi il Mio sistema si trova nell'ultima fase del ciclo di vita di un sistema spaziale, la sua dismissione. La missione è stata compiuta. Si ritorna alla base, pronti per iniziarne una nuova. Il sistema è lo stesso. Squadra che vince, non si cambia.