Project	**Application of MBSE to reverse-engineer OPS-SAT and improve OPS-SAT2**
Title	**Executive Summary Report**
Document Number	MBSE-OPSSAT-OHB-ESR
Issue	1.0
Issue Date	04.02.2022

This executive summary is written as part of the ESA study “Application of MBSE to reverse-engineer OPS-SAT and improve OPS-SAT2” contract No. 4000134685/21/NL/GLC/mk

1 PROJECT OBJECTIVES

The main objectives of the project are

- Analyse the pain points of the past OPS-SAT development and see which of those can be cured by applying MBSE methodologies
- Create a model from the existing OPS-SAT in a reverse engineering process
- Create an initial blueprint model, which can be used in OPS-SAT2 or other missions

OHB System AG (OHB, Germany) is acting as a prime contractor and interface between ESA and the consortium partners which are LuxSpace SARL (LuxSpace, Luxembourg), GPP Communication GmbH & Co KG (GPP, Germany) and the Technical University of Graz (TU Graz, Austria) providing consultancy for the OPS-SAT design.

2 OPS-SAT CHALLENGES AND MBSE SOLUTIONS

The analysis of the OPS-SAT development “pain points” has been based on

- The analysis of the “Lessons Learned” log of the OPS-SAT project
- A well-prepared questionnaire filled out by the OPS-SAT development experts
- Workshops with the experts

Pain points were sorted into groups and analysed for their potential cure by applying MBSE (Model-based System Engineering) methodologies. About 30% of the pain points identified in the OPS-SAT development were found to be resolvable by MBSE.

Please see Table 2-1 for examples of pain points and their relieve by MBSE.

Table 2-1: Identified pain points grouped by common topics and proposed MBSE solution

#	Group of Pain Points	MBSE solution
1	- Requirement traceability: manual process (spreadsheet) - Requirement V&V done manually with pass/fail criteria	Requirements can be captured in the model. Traceability to the solution can be maintained and shown in matrixes and in different types of diagrams. Extending traceability to the test cases ensures that the validated implementation is compliant with the model Tracking of issues and changes in the model as a basis for supplier communication
2	- No mechanism to see propagation/effect of a requirement change. - No requirement flow-down analysis.	Relationship between the requirements can maintained in requirement diagrams and matrixes. Use granularity levels in the model to decompose the system design. Define requirements on each level. (e.g. like proposed in SPES methodology).
3	- No functional analysis: white board brainstorming.	Create and maintain functional trees and describe the details in activity diagrams.

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4	Miscommunication between HW and SW: performance expectation mismatch	The model provides a clear deployment concept for the SW and allows early performance calculation.
5	- Lack of documentation.	The Model is the documentation. Consistent ICD specifications Being the central point of design discussion forces all team members to keep it up to date. Prerequisite: all stakeholders have access to it. Users without tool could have access via a web browser if the tool supports it. The model as a contractual basis with the supplier improves documentation and acceptance
6	- Terms on granularity (satellite, system, device, unit…): different definition depending on stakeholder. - Use of symbols not harmonized.	Using a predefined metamodel like ESA SysML Profile. The metamodel can be tailored if needed to define specific elements, stereotypes, relationships, units etc. Depending of the modeling tool a glossary can be maintained with the model.
7	- New-joiner learning curve. - Textual form for pass timeline (sequence) to save effort. - Debug time (50% of SW engineer)	A model with diagrams can be easier to read, than long documents with same content. Prerequisite the user is familiar with the modelling language and the metamodel.
8	- Behavior of component not formally specified (only getting what the supplier provides) - High learning curve to de-risk units on flatsat: abandoned by suppliers (not in their interest) - Poor documentation from COTS: do not capture edge use cases	The model can help reverse engineer the relevant structure and behavior of not formally specified components. Let the supplier provide a model of his deliverable before implementation starts. Reserve large trouble-shooting budget for deliverables which have not been integrated on model level before. Check design of deliverable based on model before integration
9	- No representative test configurations (wrong settings in flight hardware) - Configuration control: hard when lack of HR Spreadsheet used to log pre-launch configuration - FDIR: high level documented, precise parameters sit in OBSW, parameter table, spreadsheets	Configuration could be maintained in the model and configuration files could be generated automatically. Needs some conceptual and programming efforts.
10	- Protocol overhead limitation: coms bottleneck.	The model helps to understand what information is being used on both ends. The protocol can be optimized accordingly.

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3 MBSE FRAMEWORK SELECTION

Thorough analysis has been done to select the best framework for the project. The following choices have been made:

MBSE Language:

The SysML language has been selected as this is most commonly used for system designs within ESA and within the industry

MBSE Tool:

Two tools had been on the short list for this project: Enterprise Architect (from Sparx Systems) and 3DS Catia-NoMagic (from Dassault Systems). Both tools Both tools on have a good ranking for the criteria of acceptance at ESA, market share, feature set, SysML support, collaboration support and configuration control. A main difference are the licence costs which finally lead to the final down selection of Enterprise Architect.

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MBSE Methodologies:

For the OPS-SAT reverse-engineering activity the SPES methodology has been selected because of the following features:

- Compliant with the set of diagrams and methodologies of the "ESA MBSE approach"
- 4 standard views on the system: Requirements, Functional, Logical, Physical (RFLP, industry standard today)
- Granularity Level concept to manage high system complexity
- Sequence of applying the method is open and as such is ideal for "Reverse Engineering"
- Enables system modelling including Software and Hardware aspects

The SPES-Matrix keeps the diagrams in well sorted order so that navigation within the diagrams is manageable in system models of any complexity (see figure below).

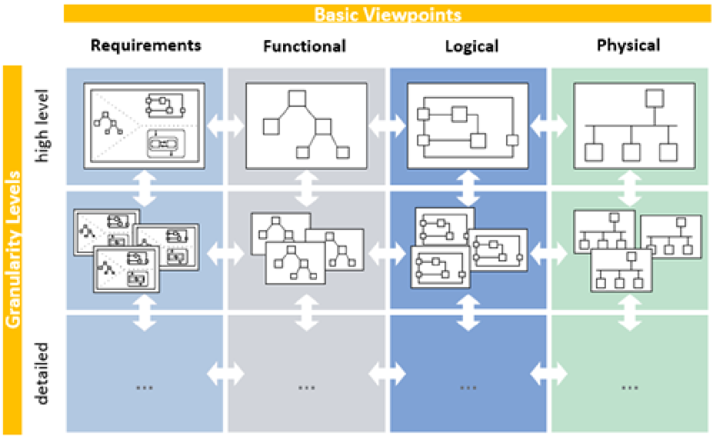

Figure 3-1: SPES Matrix

4 SYSTEM MODELLING

The Enterprise Architect Tool environment was hosted on a server by GPP Communication. All team members had access to the model. All review partners from ESA had Web-Browser access to view the model.

As a first step of the reverse engineering process, a Physical Viewpoint of the OPS-SAT model has been created based on information from available specifications. Many interviews with the experts were necessary to understand the details and fill the gaps.

The focus was on the OPS-SAT Spacecraft, but all elements of the mission had to be included to understand the context of the system on high level. The Spacecraft system was decomposed in Subsystems. Subsystems had been reverse engineered on a lower granularity level to bring more details into the model.

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The Figure below indicates how the model is being structured in the package browser of the tool. The diagrams are grouped in the levels of granularity as well as in the different Viewpoints. A graphical "Navigation Page" is being provided as an entry point for viewers of the model for an easy access to the diagrams.

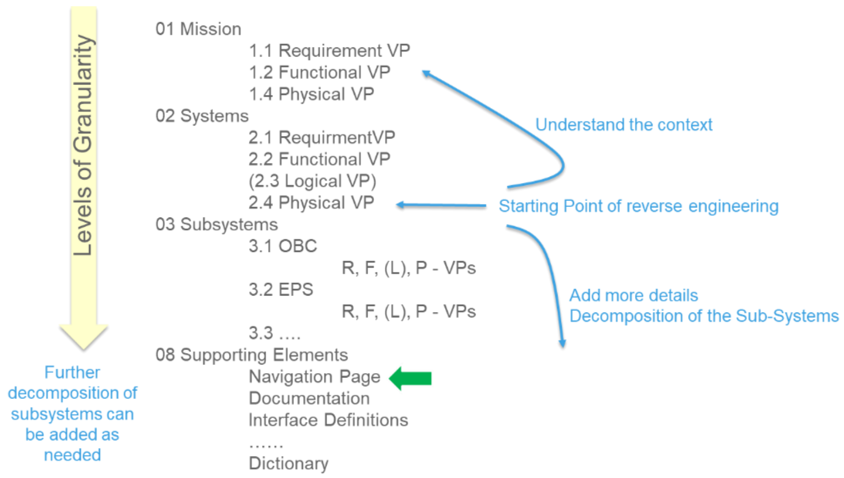

Figure 4-1: OPS-SAT Model Structure, Viewpoints and Support Elements

The Physical Viewpoints of the system and the subsystems include diagrams describing the structure (Block Definition- and Internal Block-Diagrams (Architecture)) as well as diagrams describing the behaviour of the system (State Machine, Sequence Diagram, Activity Diagram).

The physical software components are included in the block diagrams (blue frame) and are part of the processor they run on – defining the behaviour of that processor (see diagram below).This specifies the software deployment on the one hand and makes it possible to use the same software blocks of the model in the overall software architecture diagrams to specify software implementation aspects, protocol interfaces etc. on the other hand.

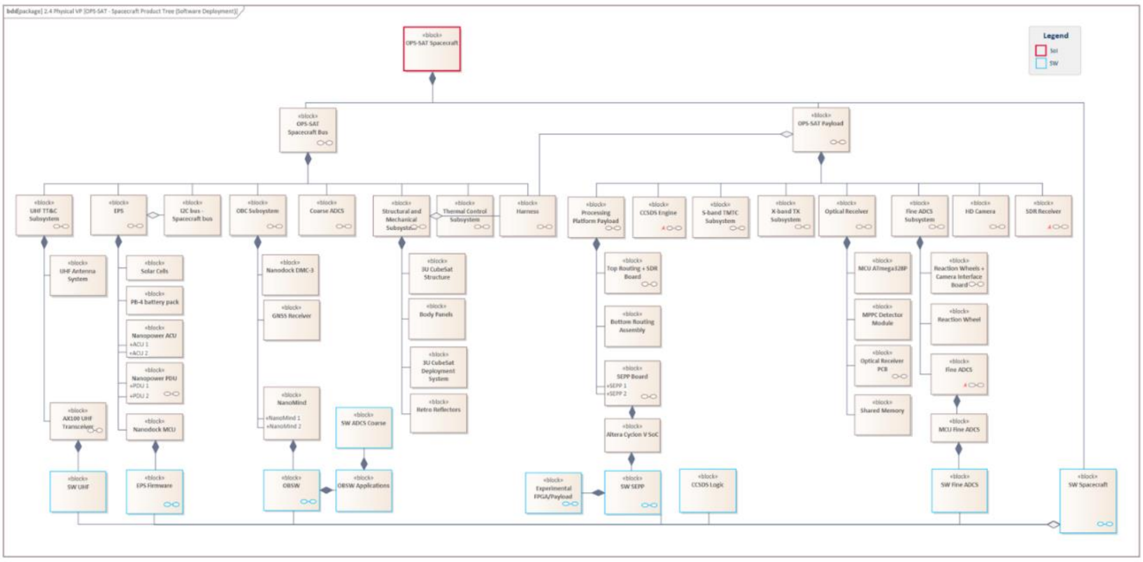

Figure 4-2: OPS-SAT Spacecraft Product Tree incl. Software components

After completing the OPS-SAT reverse engineering model, a 2nd model was created to provide an initial model for the next mission (OPS-SAT 2). All the experience from the OPS-SAT model was used to optimize the blueprint model as a starting point. The structure of the model stays the same as in the OPS-SAT model. A full set of diagram examples is included in the blueprint to provide choices of methodologies for the next mission design. The Navigation Page has been adapted to a standard set of diagrams (see below).

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Figure 4-3: Landing page of the blueprint model for OPS-SAT 2

Requirements have been imported from the OPS-SAT2 documents as an example. Further diagrams are proposed for the Requirement Viewpoint for a thorough analysis of the problem space (Use Cases, Context Diagram).

For the Functional Viewpoint several diagrams are proposed to specify the breakdown of system functions (black-box model) and the interaction between those functions (white-box model). – see diagram Figure 4-4. This allows a functional design of the systems on an abstract level without the concerns of physical impementation.

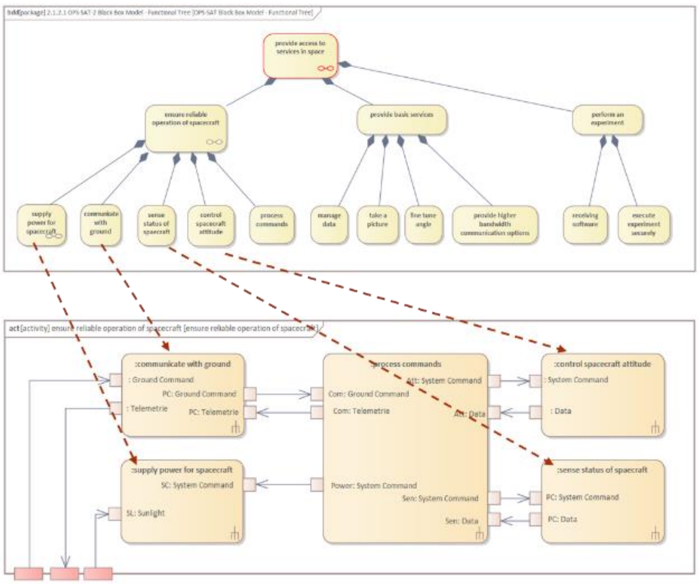

Figure 4-4: Functional Viewpoints for Function Tree and Functional Architecture

For the Physical Viewpoint the diagrams for the physical structure (Product Tree and Architecture) as well as the diagrams for the system behaviour (see State Machine Diagram below) are included as examples.

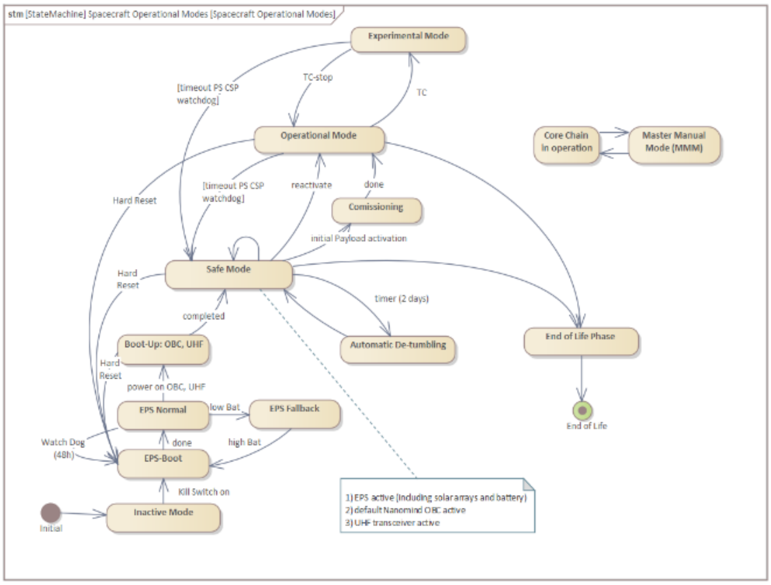

Figure 4-5: State-Machine Diagram for Spacecraft Modes and Transitions

This comprehensive set of MBSE diagrams in the OPS-SAT blueprint model provide an easy start into modelling the next mission. Details of the subsystems can be added on the next level of granularity using the same type of diagrams.

In addition, a set of supporting model features are prepared for direct use and benefit for the future project.

- Navigation Page (graphical) – for easy navigation within the diagrams of the model
- ESA Document Generation – automatic generation of documents from the model
- Traceability of Functions -> Requirements
- Traceability of Physical Elements -> Functions

Guidelines for both models are available in .pdf format explaining how the design work of future missions can benefit from the diagrams included.

5 CONCLUSION

The activity is assessed as very successful from the consortium perspective, as it was possible to demonstrate the following points:

1) Selection of a reasonable modelling framework for initial MBSE activities for new projects

The decision for the presented lean setup for the modelling framework based on COTS components for the software (SPARX Enterprise Architect) and plain SysML standard profile was at all times of the modelling sufficiently supporting the process and no missing features are identified. This can be a good indication that such a setup is reasonable for new projects and MBSE beginners and first experiences with this work approach without having to invest into too much effort for customizations or tool developments. It is expected though that this setup has its limitations w.r.t. future developments or advanced features and complexity.

2) Resolution of identified pain points by MBSE

As reported in a significant set of pain points categories are showing potential to be resolved or improved by MBSE and examples for implemented cures are presented. The main benefits are ensured data consistency, improved communication and quality of the design by supporting enhanced analysis (e.g. requirements, functional) and precise specification of the system architecture and the system behaviour. Documentation effort can be reduced significantly when the model is used as single source for the generation of other artefacts and reports.

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3) Demonstrated reverse engineering from documents to models with detailed information, but expert knowledge to interpret and understand information is required

The input documentation contained a lot of information which needed to be correctly transferred and translated into the model viewpoints. As the model does not allow for imprecision, it was easy to identify missing or not directly obvious information. Modelling should be done by experts (i.e. System Engineers / System Architects) involved in the project directly to capture the knowledge directly without the re-route over documentation.

4) Preparation of models to be re-used as starting point for future projects

The generic model template, which has been derived from OPS-SAT is a promising starting point for future projects, as it finds a balance between a pure template, which might still be lacking explanation and guidance how to use it for implementation and a concrete example for a dedicated mission.

5) Compatibility with ESA MBSE approach

The ESA MBSE Approach is the right set of diagrams covering the main MBSE methodologies equivalent to the SPES methodologies. The granularity levels of SPES are useful for the structure of complex models and are implicitly included also in the ESA MBSE Approach.

The concept of linking hardware- and software-structure in the Physical Viewpoint might be worth including in the MBSE approach.

6 FUTURE WORK

The exercise of creating a model from an existing mission gave an idea of what it takes to model a full system in SysML. It also brought up the shortcomings of existing documentation concepts and required quite some additional information from expert interviews to complete the model.

Preparing a blueprint model as a starting point for the next mission is a good preparation to make it easier for the next team to start modelling. It can also set a guideline for a meaningful model structure and standard sets of diagrams being used in ESA missions. Such blueprint model should be maintained in the future as part of the “ESA MBSE Approach” which is existing as a draft today.

The question of how much MBSE future missions should make use of, allows multiple options with increasing level of adoption:.

1) Do the documentation as usual – no MBSE
2) Do the usual documentation, but make sure all system graphical drawings are done in SysML
   Maintain one model-file for all SysML drawings of the mission
3) Replace one System Design Document by a SysML model
   Generate the Spec automatically from the model
   Maintain the model throughout the project including all changes
4) Do all project documentation in a model
   Request a model from every supplier before delivering the component

Option 2) is a good starting point if many engineers need to get familiar with the SysML language and the usage of the tool. It allows to do first connections between the drawings and reuse parts of drawings and concepts. With this option the usual development process can stay as is.

Option 3) relies much more on the model as a central documentation for the engineers working on the design of the mission and the systems. This level would provide more MBSE benefits in terms of collaboration on a central model representing the full design of a system (towards a digital twin).

Potential for future work can.be divided into two categories: a) improvement of tooling and model fidelity and b) change management and implementation in projects.

Tool and model related future work

A central model can be used to organize and orchestrate co-simulation by introducing Parametric Diagrams specifying expected input from and output to linked simulation tools. With this, it would be possible to run

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model-based trade studies across several disciplines, e.g. capitalizing on commercial tools and plugins or current developments within ESA. The generation of views on the model (i.e. budgets, respective graphs, dashboards) directly inside the SysML editor or other application shows direct benefit as it would ensure a central source for system relevant parameters and further improve data consistency and reduce the effort.

By extending the document generation capability a significant reduction of documentation effort can be achieved. The documents identified with high MBSE potential (e.g. the System Design Report) could be generated from the model.

From a certain level of MBSE expertise and profession within an organization, it may become necessary to extend the plain SysML profile with customizations (e.g. standard parameters or naming conventions) to ensure compatibility with organizational methods and heritage tools and re-use across projects

Change management and project application

The development of MBSE awareness and experience within an organization is key to start a change process from the classical, document based work approach towards model-based (systems) engineering. It is important to not only convince MBSE enthusiasts about the benefits but also engage regular users.

Once a mission decides to use a model for specification it is very important to take the model as the single point of truth and keep it up to date throughout the lifetime of the mission.

It is recommended to have a “Model Master” in place who provides guidance to the contributors of the model and maintains the consistency of the model.

For missions coming up the members of this project team (OHB, Luxspace and GPP communication) are happy to assist with coaching or Model-Master support.

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