# First lessons learned from adopting a Model-Based System Engineering approach in early phases of complex satellite systems

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This paper presents the Model-Based System Engineering (MBSE) methodology, language, and tool adopted as part of the system engineering framework used in the early phases European Leo Component for Assured NavigatiOn (ELCANO) are presented. ELCANO is the first initiative for a European satellite component in LEO orbit to augment the existing European GNSS infrastructure (i.e., Galileo and EGNOS) by providing resilient and robust ranging signals for assured Positioning, Navigation, and Timing (PNT), while also considering improved performance (e.g. higher availability, faster time-to-fix, reception in indoor and difficult environments) and new added-value services.

Traditional satellite navigation systems are dominated by mission-centric risk adverse programs, usually resulting in high costs and long development times. In recent years, driven by commercial needs, non-traditional aerospace ventures have worked to develop faster and cheaper access to space for broad range of applications and services. Examples of this are Megaconstellations like OneWeb and Starlink. The complexity of ELCANO lies not only in making it interoperable with the existent GNSS technology but also in bringing the traditional space model into the Space 4.0 concept with lower costs and fast dynamic development. One of the challenges ELCANO faces, is to provide services on par with existing GNSS but from much smaller platforms, payload, and antennas, all this while increasing the autonomy of the satellites in order to limit the complexity of the Ground Segment. New satellite innovation (e.g. functionality, size, launch options, in-orbit control) and scaling down (size, power, cost) while keeping services quality on par with traditional GNSS (larger, more powerful, less risky, etc.) brings with it many challenges in the system engineering work.

Mastering the complexity of a project as ambitious as ELCANO, with many users, stakeholders, lower costs, and demanding requirements, is a challenge for the traditional System Engineering approach.

With the aim of supporting the management of requirements and conceptual design analysis and to link the mission drivers to the design justification, a MBSE framework approach has been used to model the primary and secondary missions and the system analysis. This has been achieved by applying Arcadia (Architecture Analysis & Design Integrated Approach) methodology and Capella tool.

Arcadia is a MBSE methodology fully based on SysML (Systems Modeling Language) but it provides a more simplified and enriched interface to allow a better comprehension for users that are not computer scientists. Arcadia is aimed to define and validate the architecture of complex systems. Iteration through the models is encouraged in order to match the needs of the customers regarding the System of Interest and consequently enable higher communication and a collaborative approach between stakeholders.

The fact that tool, language and methodology are incorporated in a single MBSE software program facilitates the final choice of the most suitable methodology. In addition, Capella presents a friendly user interface, that eases the first step of the system modelling, allowing to check the adequacy of the prototype system relatively to the mission requirements. The first steps taken to model the system consists in models have been done at the first two perspective levels: Operational Analysis, and System Analysis while the Logical and Physical architecture will be gradually introduced as the mission life cycle will evolve to next phases.

In the Operational Analysis actors, their activities, constraints and interactions have been identified. At this first issue of the model, the focus is placed on a group of application areas from the traditional user segment of a GNSS system, selected based on their needs currently addressed by GNSS only partially or not at all. These strategic sectors are modelled as Operation Actors of the system and their needs are driving the definition of mission requirements. Besides the user segment, several other stakeholders are identified: design authorities, operator, regulatory bodies, etc. to explain the interaction between ELCANO User Segment and the system.

The use of Capella allowed for the construction and maintenance of a global coherent vision of ELCANO system, in addition to integrate operational and system views together with the associated viewpoints of all the stakeholders. The methodology helped the authors to identify and classified the multiple stakeholders and user types and to establish the perimeter targeted by this Phase 0 study.

For complex systems there could be thousands of documents that need to be created and maintained throughout the system life cycle. These documents are used by systems engineers during the various stages of the system development process and their production, and maintenance require significant effort from all parties. They help with determining what information needs to be communicated by one team to another during system development and therefore contribute directly to the schedule and costs of a mission. Since the data represented in these documents do not have explicit dependencies, a change in one document needs to be reflected manually in all the other affected documents. This manual process is not only lengthy but also prone to error. Furthermore, when documents are used to facilitate communication, it is difficult to verify their completeness and consistency, and to surface conflicting or contradictory information.

This problem has been overcome in ELCANO by using M2Doc, an open-source add-on by Obeo that is used directly in Capella. M2Doc takes Word templates written in a language built on top of AQL as inputs to generate documents automatically directly from the model. It enables flexible and custom document generation. In this way, the documentation of the project is well aligned with the model, allowing traceability. A change in the model will be reflected in the document generated. This add-on has also enabled to produce documents to track the progress of the model.

For a Phase 0, the system engineering function according to ECSS Standards shall support the Mission Definition Review and ensure the implementation of its actions. For this purpose, M2Doc has been used to integrate the model in Capella with this analysis and maintain it up to date with the last changes of the Mission Description Document, which contains user needs and requirements. At this stage, the documents writing is not as heavy as in later phases of a space project. However, as documents for future project milestones are going to be generated from the model, the templates should be defined early, as they will influence many future modelling decisions.

It has been learnt, that if certain information wants to be extracted from the model to a document, it must be stored in Capella in a field that can be accessed by the M2Doc tool. Moreover, the naming of functions and diagrams with consistent identifiers is very important to automate the extraction of information as much as possible. System designers need to know where to store the model elements and any metadata or links that may be used for queries, document generation, or compliance. As a best practice, create a high-level, full-system skeleton model early to validate these usage scenarios. Then, the teams will be able to populate the model as the system evolves.

On one hand, there is limited M2Doc documentation available and to become an independent template developer is a very time-consuming task. On the other hand, M2Doc proved to be a very powerful tool to automate the model documentation once a generic template is created. Every piece of information available in the Capella model can be extracted to a Word Document with the click of a button. In the authors experience, the tool has been proved to be truly helpful to ease the production of large documents for important project milestones. Despite the fact that the learning curve is steep, M2Doc has been demonstrated favourable for space projects documentation. Because of the time invested to master the tool, it is not necessary that every member of the system engineering team knows how to code an M2Doc template. This expertise can fall on one or two members that manage the tool skilfully.

The camera-ready manuscript will detail on the challenges encountered during the development and lessons learnt. To continue, we will report on the experience of using M2Doc to generate documentation for industry activity, track the progress of the model and extract information and diagrams from the model to ESA templates. Finally, we will introduce the steps to follow for Logical and Physical levels of the model architecture.