ESA SysML solution : Specification and Implementation

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1 Introduction

1.1 Purpose

This Executive Summary Report (ESR) is a deliverable in the frame of the ESA SysML. The purpose of this document is to provide a summarized description of all the work done during the activity and is self-standing. It covers the entire scope of the work including the context, the description, the activities performed, and the main results achieved.

1.2 Overview

In the first section of the document provides the description of the contest of the activity, followed by the work logic, the schedule and delivered outputs. The document then describes in detail the activities performed and concludes with the results and conclusions.

2 Applicable and Reference Documents

2.1.1 Applicable Documents (ADs)

Table 2-1: Applicable Documents

AD	Document Title	Reference
[AD1]	Statement of Work	

2.1.2 Reference Documents (RDs)

Table 2-2: Reference Documents

AD	Document Title	Reference
[RD1]	MBSE at ESA: State of MBSE in ESA Missions and Activities	https://indico.esa.int/event/386/timetable/#5-mbse-at-esa-state-of-mbse-in
[RD2]	OMG SysML	https://www.omg.org/spec/SysML/1.7
[RD3]	ECSS - Engineering design model data exchange – CDF	ECSS-E-TM-10-25
[RD4]	ECSS - Space system data repository	ECSS-E-TM-10-23A
[RD5]	ESA MBSE Evolution: From ESA SysML Toolbox to ESA MBSE Solution	https://indico.esa.int/event/386/timetable/#6-esa-mbse-evolution-from-esa
[RD6]	Requirements Interchange Format	https://www.omg.org/spec/ReqIF/About-ReqIF/
[RD7]	ECSS - Interface management	ECSS-E-ST-10-24C

AD	Document Title	Reference
[RD8]	ECSS - Verification	ECSS-E-ST-10-02C Rev.1
[RD9]	ECSS - System engineering general requirements	ECSS-E-ST-10
[RD10]	ECSS - Technical requirements specification	ECSS-E-ST-10-06
[RD11]	ECSS - Glossary	ECSS-E-ST-00-01
[RD12]	ECSS - Project planning and implementation	ECSS-M-ST-10

2.2 Terms, Definitions and Abbreviations

Term	Definition
ESA	European Space Agency
SysML	System Modelling Language
MBSE	Model-Based System Engineering
SME	Small and Medium Enterprise
ECSS	European Cooperation for Space Standardization
DOORS	Rational Dynamic Object Oriented Requirements System (IBM software)
CSM	Cameo Systems Modeler
EA	Enterprise Architect

3 Context

3.1 Background

Model-Based System Engineering (MBSE) is a paradigm of engineering that gather methodology and tool to develop Digital engineering. Indeed, the development of systems a few decades ago, was mainly done with paper and very few computing power compared to today. With the growing use of technologies in different specific domains – such as Thermal domain, mechanical domain – the need of a unique source of truth to refer to check requirements became needed. Requirement management was put in place but nowadays referring to these requirements through different tools (namely DOORS, or sometimes Excel) became highly difficult.

Since mid 2010, the European Space Agency (ESA) has been developing MBSE to increase the use in the Agency, develop systems faster, and streamline the development process. **[RD1]** presents the

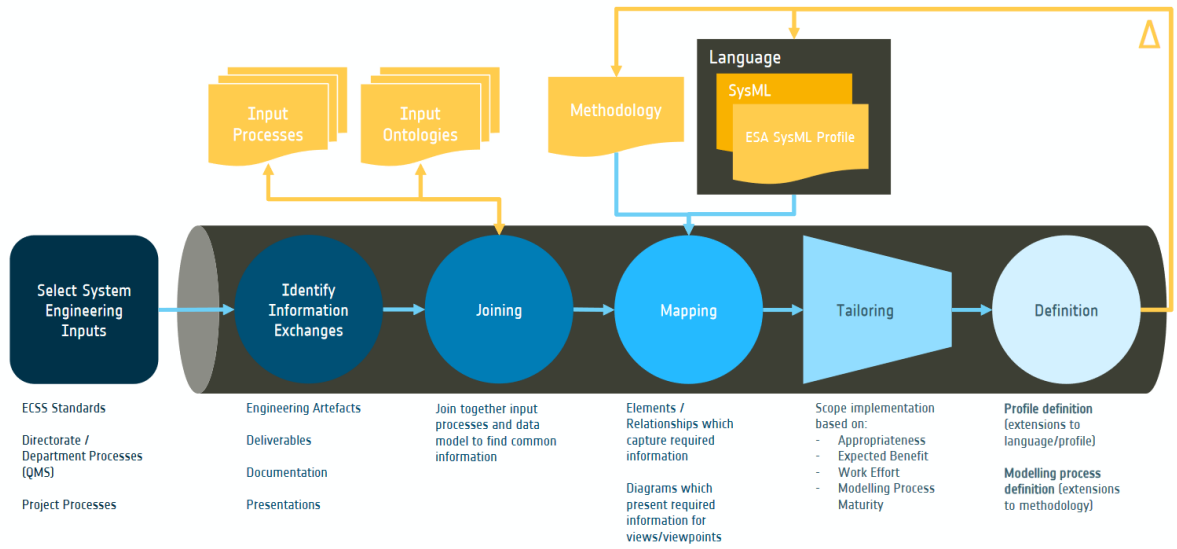
status of MBSE at ESA. To this extent the System engineering section at ESA developed the ESA SysML profile, a customized version of System Modelling Language (SysML) **[RD2]** help with system development, adapted then to the different projects requiring MBSE.

In addition of the profile, ESA developed a toolset for Enterprise Architect to bridge the gap between the tool itself to other engineering tools. For example, the toolset allows to export ReqIF files for importation to another system such as DOORS or Polarion. It allows also the import and export of Excel files as Enterprise Architect lacks features to persist matrixes or to present correctly a list of requirements.

Several iterations of the ESA SysML profile have been developed; all the iterations are developed through a pipeline to ensure the conformance of the profile to the ECSS documentation. The pipeline involves:

- Engineering inputs
- Identification of Information Exchanges,
- Joining the input processes
- Mapping on to a target language
- Tailoring the profile to the needs
- Definition of the profile
- And eventually, a feedback loop with the target language to refine the profile.

The pipeline is shown below, taken from **[RD5]**.



This pipeline has two main benefits: it gives a SysML meaning to ECSS documentation, as it is based on current standards and it provides a procedure to make any changes on the profile.

3.2 Objectives and Scope

Additionally, as SysML v2 has not been released at the time of development of the language, the implementation will take place onto SysML v1, as to latest minor version.

To respect the pipeline described above, the work has been divided into 2 phases: specification and implementation.

4 Program of work

4.1.1 Phase 1 - Specification

This phase covers the specification of the ESA SysML profile. Standards documentation have been analysed to feed the pipeline. As ESA already developed the first iterations of the specification, the same pattern has been applied to the specification, therefore the analysis of the ECSS documentation has been done in a similar way to represent the ECSS documentation. To ensure the consistency of the representation, the previous analysis and mapping are analysed and based modelling rules made at the moment of the first iteration of the ESA SysML Solution.

The analysis has been done on Cameo System Modeler Models and comments are reported directly on the models. Discussions are made during the sprint reviews and during technical meetings that took place in between.

Once the analysis models are stabilized, this leads to the next steps which are the joining and mapping tasks. New concepts identified in the analysis are reported in Nexus, and the mapping to the target language is also defined here. Conform to the pipeline process, at this step conformance to SysML and methodology is checked to ensure the implementation on the target language. As it is an iteration of the profile, only additions to the profiles are to be done for the compatibility with the previous version of the profile.

4.1.2 Phase 2 - Implementation

Once the specification of the profile is fixed, implementation of the profile can be done on the two target tools: Cameo Systems Modeler and Enterprise Architect. As the mapping to the target language has been specified in the Nexus model, only the implementation must be done, and the validation of the implemented profile has to be done.

4.1.2.1 Cameo Systems Modeler implementation

The previous iteration of the ESA SysML Solution was made on Cameo Systems Modeler. Thus, on this iteration only additions are needed and a proper plugin for Cameo containing the profile has been built.

Any naming needs to come from Nexus, Nexus being the source of truth, and to keep the consistency between Cameo and Enterprise Architect.

Additionally, the Nexus profile specifies several derived properties. The tool provides the capability to make derives properties automatically filled depending on the relationships of a block in the model.

Once the validation done, the user manual, the guide for user support has been written to allow anyone to reproduce the plugin, personalized to the user's needs.

4.1.2.2 Enterprise Architect implementation

No implementation of ESA SysML Solution has been made on Enterprise Architect. There is only an implementation of the ESA SysML Toolbox v3 on Enterprise Architect.

As the implementation is non-existent, the objective is to keep the as much as possible the consistency between Cameo and Enterprise Architect, in terms of profile implementation and in terms of visualization (icons, colors).

At the end of the development, the validation of the profile takes place. It is also at this moment, that the implementation may be modified to be close to the implementation of SysML in Enterprise Architect.

Once the implementation is validated, the plugin development can start as the profile is stabilized.

For ESA SysML Toolbox v3, there was a tool coded in Python to:

- import requirements from Excel
- export requirements to Excel, Word and ReqIF **[RD6]**
- export change log (see all differences from a baseline)
- export the traceability of requirements (e.g. see all derived requirements from a Package)
- change colors of elements in a batch way
- profile migration from ESA SysML Toolbox v2 to v3

A similar tool must be developed for ESA SysML Solution, taking the previous tool as a baseline. The previous has been deemed not user friendly, and the choice of an Enterprise Architect plugin has been chosen. The choice went to a C#-developed plugin as it would blend in Enterprise Architect. To ease the future changes in the profile, the plugin has been developed with a configuration file to be modified to add eventually elements in the exports.

Similarly to the Cameo plugin, the user manual, and the guide for user support has been written to allow anyone to reproduce the plugin, personalized to the user's needs. Documentation also contains instructions to change the configuration file.

5 Main results Achieved

5.1 Interface and Verification Domains

The extension of the interface and verification domains is a system and solution version 1.1 has been made with respect to ECSS **[RD7] [RD8].** This project successfully made another iteration to the ESA SysML Solution and it improved the representation of interfaces and developed the verification domain in the ESA SysML solution.

Additionally, the extension of these domains integrates into the current ESA SysML solution by following the pipeline set by the previous iterations. The development of these domains has been done in conjunction with a prime supplier and model-based system engineering experts. The development of the ESA SysML solution helped in defining ECSS in the profile domain specific language, specific for a space system.

Indeed, ECSS normative document were transcribed into an analysis model, but only few concepts were transcribed into to the Nexus model. Several iterations happened on the analysis model to be sure about the reading of ECSS standards. The analysis of the standards also showed that it may be sometimes fuzzy. The fuzziness of ECSS standards may lead to inconsistent models. To reduce the number of inconsistencies made by the system modeler, less system engineering concepts were represented into the data meta-model.

Additionally, methodology pages in the form of web pages or PDF documents were produced to help the system modeler in representing their system, considering that the system modeler has ECSS knowledge. The methodology page is also containing the instructions to use the profile in Cameo Systems Modeler and in Enterprise Architect.

In the verification domain, an analysis has been performed and several classes were added to collect the verification process, the requirements processes verifies and the result of the verification test.

In the interface domain, an analysis has been performed most of the elements are already present in the nexus Model. Only few elements were added, such as the responsible organization, and derived properties.

5.2 Cameo Systems Modeler Profile

A Cameo Systems Modeler profile was already existing in the previous iteration of the ESA SysML Solution. During the activity, the objective was to update that profile and to create a plugin for cameo system modeler to ease model exchange.

5.3 Enterprise Architect Profile

A major part of this activity was made on Enterprise Architect. Indeed, the ESA SysML solution did not contain a profile for Enterprise Architect. An objective of this activity, was to recreate the profile in Enterprise Architect, enable constraints in the profile and create the toolboxes.

Indeed, Enterprise Architect comes with profile modelling capabilities but also with constraints checking during the modelling process. This enables the compliance of the model with the ESA SysML Solution profile.

Another part of the modelling includes the toolbox creation to ease the creation of a model by system modelers.

Afterwards, profile is generated to be ported to any Enterprise Architect instance.

5.4 Enterprise Architect Plugin

As an addition to the profile and Enterprise Architect, we propose also an Enterprise Architect plugin. As of the previous version, the ESA SysML toolbox v3, there was a toolset used to provide more functionalities for requirement management as Enterprise Architect does not natively provide enough capabilities such as ReqIF export, management of profile attributes in Excel or Profile upgrade.

With the developed plugin, several functionalities are taken from the previous toolset and improved.

5.4.1 Import and export requirements

Previously, import and export were separated, and round tripping was not available. We have developed a plugin that allows the export of requirements onto Excel or ReqIF, make additions, deletions, modifications on the spreadsheet or the ReqIf file, and reimport the requirements back to Entreprise Architect, without using synchronization values (GUID in an element's properties). All changes made on the file are then implemented in the model file.

It is also possible to choose the fields to export to reduce then the amount of data to show or share in the spreadsheet.

During the import, using the export as a baseline file, a pre-processing happens to check any inconsistencies in the import file and warn the user about the changes that will be done on the model. Warnings can be exported to process the errors/warnings separately.

5.4.2 Traceability

Additionally, it is also possible to export the derived requirements from a package and then see what the impact of a requirement on all the requirements in the model is. The current implementation shows only one step of derivation.

An example of traceability is shown below:

Environmental Specification	Text	"Derives to" Data Exchange Specification
9	The Hold-Down and Release Mechanisms (HDRM) shall be used to maintain the Solar Array rigidly fixed to the spacecraft structure during launch.	Requirement 7

5.4.3 Export Change log

Another feature is the change log: using Enterprise Architect to create baselines, and to compute differences, this feature shows the difference between a baseline and the current model, and save the changes on the model. This allows the documentation of changes on the model.

5.4.4 Change colors

This feature, present in the previous toolset, allows to change the color of all elements in a package (or all selected elements). That is to show the different layers or specifications in a diagram through the colors.

5.4.5 Model validation

This new and experimental feature checks the model on some constraints present in the profile. This feature helps systems modellers to get a system compliant with the ESA SysML Solution. Running the validation toolset gives in the log all elements that are not compliant with the ESA SysML Solution.

6 Identified future work

As for the profile, more domains can be added in the profile to address more domain of expertise. For example, elements are not quantified. It would be then logical to involve Concurrent Design models **[RD3]** in the loop to enable MBSE from pre-phase 0. An identified work is then to conduct Concurrent

Design sessions with ESA SysML Solution from the beginning to prepare Models at this stage and then reuse this model in later phases of the project. In the event the model is not reused, it can be used as a library of mission and then digitalize the Concurrent Design Facility reports.

Another future work is the use of SysML v2 as a baseline language for the ESA SysML Solution. As the current implementation is done on Cameo Systems Modeler and Enterprise Architect, a future work can be providing an example of a model in SysML v2 and the ESA SysML Solution.

Additionally, making the ESA SysML Solution part of an ECSS standard would enforce the use of the solution, and the methodology in space projects which would spread the use of MBSE among the space community.

As for the Enterprise Architect profile and plugin, this enables the use of the ESA SysML Solution to SMEs. As ESA must lead the way to uniformize processes in projects, the Enterprise Architect plugin must be developed. As the plugin has been developed independently of a profile, it can be reused to other profiles. A configuration editor would be useful to modify the configuration file using the editor and visualizing the modifications. Additionally, if the model is located on a server, configuration would be saved on the server and then a pool of configurations would be available for each project that has a specific version of the profile tailored to their needs.

Currently, the methodology is located on pdf files or on a website on ESA premises. To ease the modelling of systems in Enterprise Architect, a modelling assistant where all packages and diagrams could be created automatically to follow the methodology can also be a possibility to enforce the methodology from inside Enterprise Architect.

The import and export of ReqIF files has been done using the toolset for ESA SysML Toolbox v3 as a baseline. The implementation of the export of ReqIF files is not consistent among the tool vendors (DOORS, Cameo Systems Modeler, Polarion, etc). Because of this, the export from Enterprise Architect can be done, can be read by the tools, but cannot exchanged smoothly between the tools. Therefore, adapting the ReqIF to the different “flavors” given by each tool would enable the interoperability of requirements (from the ESA SysML Solution).