ITEA2 Project
Call 6 11025
2012 – 2015

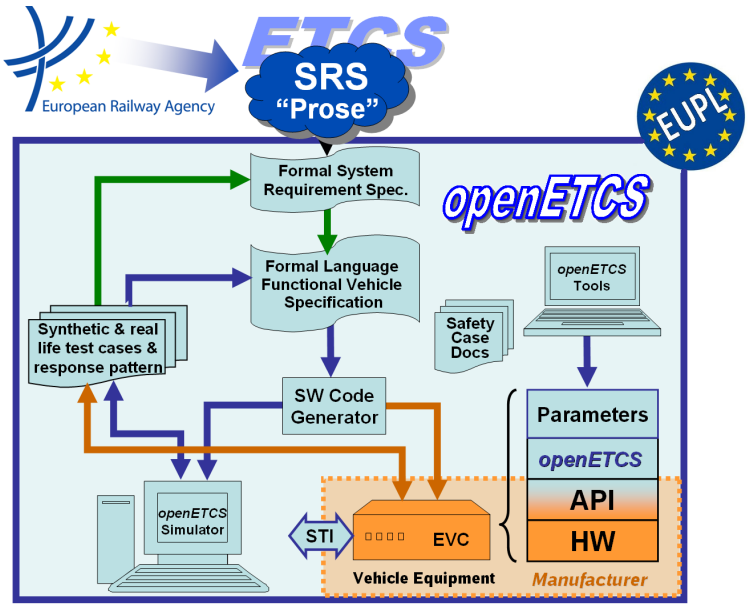
Work Package 7, Task 1: “Primary Toolchain”

Report on the Final Choice of the Primary Toolchain

Decision on the final choice for the means of description (O7.1.4), tools (O7.1.8) and tool platform (O7.1.11)

Michael Jastram, Marielle Petit-Doche and all participants of the decision process

October 2013
Revised November 2014



Funded by:

Federal Ministry of Education and Research
Région de Bruxelles-Capitale
GOBIERNO DE ESPAÑA
MINISTERIO DE INDUSTRIA, ENERGÍA Y TURISMO

This page is intentionally left blank

Work Package 7, Task 1: "Primary Toolchain"

OETCS/WP7/D7.1 – 02/00
October 2013
Revised November 2014

Report on the Final Choice of the Primary Toolchain

Decision on the final choice for the means of description (O7.1.4), tools (O7.1.8) and tool platform (O7.1.11)

Document approbation

Lead author:	Technical assessor:	Quality assessor:	Project lead:
location / date	location / date	location / date	location / date
signature	signature	signature	signature
Michael Jastram (Formal Mind)	Michael Jastram (Formal Mind)	Cécile Braunstein (University of Bremen)	Klaus-Rüdiger Hase (DB Netz)

Michael Jastram
Formal Mind

Marielle Petit-Doche
Systerel

all participants of the decision process
WP7 partners

Deliverable

Prepared for openETCS@ITEA2 Project

Abstract: This document gives a description and the results of the first task of WP7. The objectives of the task are to analyze and recommend, means, tools and platform to develop the primary toolchain of Open ETCS.

Modification History

Version	Se	Modification / Description	Author
00.01		08/07/2013 Document creation	M. Petit-Doche
00.02		18/07/2013 Complements in § 3	M. Jastram, C. Braunstein
		Draft version of appendix A	U. Steinke
00.03		19/07/2013 Complements in § 2 and § 4	M.Petit-Doche
00.04		31/07/2013 Significant work in §§1, 2, 3 and 4 before review.	M.Jastram
00.05		13/08/2013 Github issues taken into account: 80, 84, 87, 88, 89, 90(partial), 96 107	M.Petit-Doche
00.06		15/08/2013 significant review of Papyrus-ERTMSFormalSpecs-Eclipse proposal	Stanislas Pinte
00.07		26/08/2013 Cleaning in all the document Github issues taken into account: 82, 83, 90, 100, 112, 116, 119	U. Steinke, M. Petit-Doche
00.08		29/08/2013 Cleaning in all the document Github issues taken into account: 85, 99, 100, 123, 124, 126	M. Petit-Doche
00.09		03/09/2013 Cleaning in all the document Github issues taken into account: 62, 102, 126 (partial), 132, 136	M. Jastram, M. Petit-Doche
00.10		03/09/2013 Description: Image of SysML / Classical B toolchain updated. Minor updates in text.	A. Stante
00.11		03/09/2013 Cleaning in all the document Github issues taken into account: 86, 108, 116	M. Petit-Doche
00.12		05/09/2013 Issue taken into account: 118	A. Stante
01.00		05/10/2013 Rewrite according to Review meetings and issues, in order to start the second review round.	M. Jastram
01.01		12/09/2013 Issues 139, 144	M. Petit-Doche
01.02		12/09/2013 Review, Decision and Resource Allocation	M. Jastram
01.03		13/09/2013 Issues 142	M. Petit-Doche
01.04		13/09/2013 Issues 75, 153	M. Petit-Doche
02.00		01/10/2013 Major version for 2nd decision meeting	M. Petit-Doche
02.01		26/11/2014 Updating the template for compliance.	Michael Jastram

Table of Contents

Figures and Tables

Figures

Tables

Document information	
Work Package	WP7
Deliverable ID or doc. ref.	D.7.1 (including O7.1.4, O7.1.8, O7.1.11)
Document title	Report on the final choices for the primary toolchain
Document version	02.01
Document authors (org.)	Michael Jastram (Formal Mind), Marielle Petit-Doche (Systerel) and WP7 partners

Review information	
Last version reviewed	02.01
Main reviewers	See Revisions

Approbation			
	Name	Role	Date
Written by	Michael Jastram Marielle Petit-Doche Cécile Braunstein Uwe Steinke Stanislas Pinte Alexander Stante	WP7 Task Leader WP7-T7.1 Sub-Task Leader	October 2013
Approved by	Michael Jastram	WP7 leader	October 2013

1 Introduction

The aim of this document is to report the results of the task T7.1 of WP7: “Primary Toolchain Analyses and Recommendations”.

1.1 Executive Summary

The task of WP7 is to produce an integrated chain of software tools that covers according to the approved openETCS FPP all artifacts needed to formalize, modeling, software generation and verification and validation of the entire ETCS System Requirement Specification (Subset 026 and supporting subsets).

To simplify the selection process, this has been separated into a primary and secondary toolchain in the WP7 Description of Work (DoW) [4]. This document is concerned with the selection of methods and tools for the *primary* toolchain, which are means and tools to specify and design a critical system from the system specification to the executable code. Secondary methods and tools selection concerns means to complete the toolchain to obtain a proper engineering environment for the development of critical systems: thus means and tools for verification and validation activities, to support safety analysis or data or requirement management will be analyzed during this second phase. As the tools shall be integrated, the selection of an integration platform was required as well.

Eclipse was selected as tool platform, and the decision was unanimous, see Section 3.

Use of SysML and Papyrus for the highest level of specification was also a unanimous decision, see Section 2.2.3.

Three toolchains have been proposed to complete the use of SysML and Papyrus, which will be referred to with the following shortcuts for brevity:

SCADE. This toolchain is based on SCADE in connection with Papyrus, for which an integration already exists.

EFS. This toolchain is based on ERTMS Formal Specs (EFS), in connection with Papyrus, for which an integration has to be developed. It will take advantage of elements from the Eclipse ecosystem (and from TOPCASED, wherever possible). The methods for integrating the various models have to be developed, as well as the gluing code that will hold everything together.

B. This toolchain is based on B in connection with Papyrus, for which an integration has to be developed.

SCADE is the perfect candidate for a backup plan: While offering pretty much everything the project needs, it has a major drawback: SCADE is not open source. At the same time, SCADE is a backup that could be activated very quickly. It is preferable to model successfully with a closed-source solution than to fail with an open one. But of course, modeling successfully with an open source solution is what we should strive for.

As all three solutions use Papyrus as the first modeling tool, activities should focus on narrowing down which elements of Papyrus should be used. Once this is clear, WP3 can get started with their modeling activities.

Some effort needs to be spent on defining the interfaces between the various tool elements. This has been demonstrated nicely by the B-team, as visualized in Figure C1. The EFS-team updated their proposal with a similar picture.

The interfaces of the three toolchains should be aligned as much as possible. Doing so will allow to switch tool components between the three toolchains with comparatively little effort, if the need arises.

Once the toolchains are defined in detail, a pilot model will be created using the B and EFS toolchains. This pilot will be the foundation for deciding on one single toolchain, by the end of 2013 the latest.

Section 4 contains specific decisions intended to concisely guide activities until the end of 2013.

1.2 T7.1 Objective

The goal of WP7 is to provide other openETCS work packages with tooling for their activities. Tools have been separated into primary and secondary tooling. Task T7.1 is concerned with the identification of the best primary tooling, considering all constraints of the project. Selecting tools also entails selecting modeling languages and an integration platform.

1.3 Scope of Task T7.1

The scope of the primary tooling has been defined in the WP7 Description of Work [4]. Figure 1 depicts the main process (taken from [5], for more details on the process and the meaning of

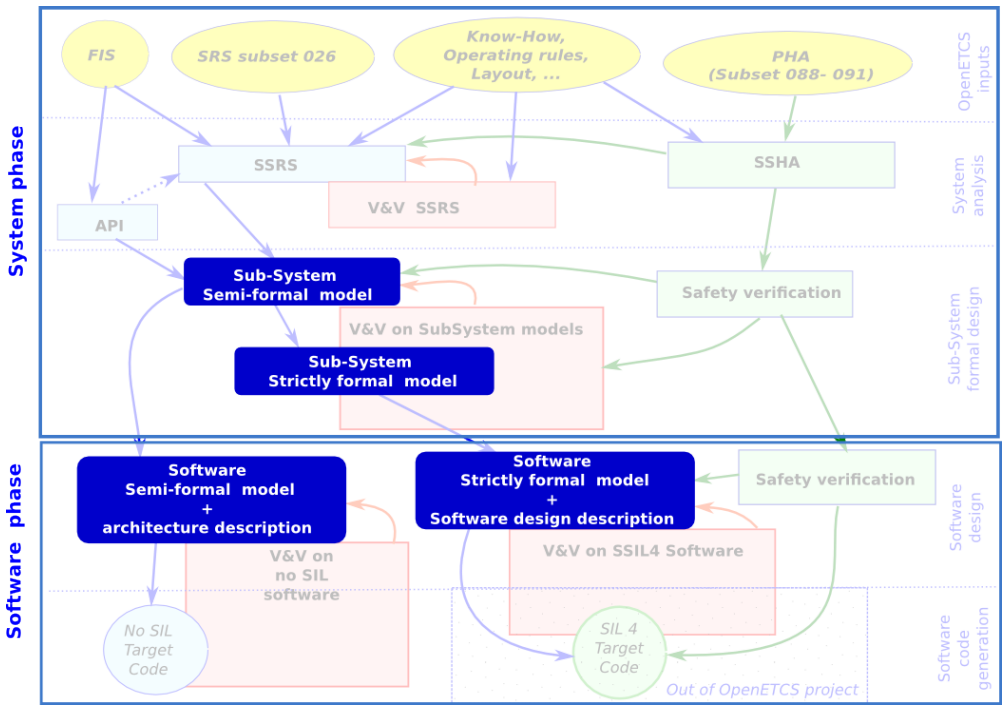


Figure 1. Main OpenETCS process. The models that are covered by primary tooling are shown in blue.

formal methods, please to look at [5] and [7]). In the scope of the primary tooling are (according to the DoW):

Sub-System Semi-formal model. "A semi-formal model of the system specification is defined from the SSRS. This model shall reflect the architecture defined in SSRS. (...) The semi-formal model shall be as consistent as possible with the SSRS level of abstraction, in particular choices concerning software architecture and design have not to be described at this level. In practice, all the requirements of SSRS and of the sub-system Hazard analysis shall be covered by the semi-formal model." (D2.3, 4.4.3). In particular the architecture shall allow "to classify Vital versus Non-Vital items (functions, input/output, requirements, ...) from the safety analysis results" (D2.3, 4.3.3). "This model shall reflect the architecture defined in SSRS " (D2.3, 4.4.3). "The means of description of the semi-formal model shall be understandable by domain experts, providing graphical description" (D2.3, 4.4.4).

Sub-System Strictly formal model. "This semi-formal model *can* be extended with strictly formal models to improve the understanding of some part of the sub-system." (D2.3, 4.4.2). "To facilitate safety activities, the safety relevant function should be as much as possible insulated from non safety relevant functions." (D2.3, 4.4.3).

Software Semi-formal model + architecture description. The main output of this step is a semi-formal model which allows to produce executable code. "This model shall be completed by a Software Architecture and Design Specification, which describes the software architecture and the design choices. (...) The semi-formal model defined during the system phase shall be completed, keeping the same language or extending it to cover specific software aspects." (D2.3, 4.5.2).

Software Strictly formal model + Software design description. This model is concerned with the functional and safety branch. This activity "shall provide methods and a toolchain to obtain SIL4 executable code of the on-board software application." (D2.3, 4.5.3). Inparticular T3 class tools shall be necessary to automatically produce SIL4 code form software model.

1.3.1 Scope with respect to SSRS, API and code

API, Code and SSRS[1] are in the scope of the secondary toolchain (T7.2). Choices in the primary toolchain that may affect the secondary toolchain will be covered in this document.

The SSRS poses a special challenge, as activities in its creation have already started. However, no tools have been selected yet. Deliverable D2.3 [5] describes the form of the SSRS as follows: "The SSRS (...) shall be described as textual documents." (D2.3, 4.3.4). It continues to state: "However these documents shall be completed by a semi-formal model to describe the functional architecture of the on-board unit".

The connection between SSRS and Sub-System Semi-formal model is described as: "A semi-formal model of the system specification is defined from the SSRS. (...) In practice, all the requirements of SSRS and of the subsystem Hazard analysis shall be covered by the semi-formal model."

There is even less information regarding the API, except that it is handled corresponding to the SSRS: "The SSRS and API shall be described as textual documents. However these documents

[1] Note that the DoW does not even mention the SSRS, as its creation has been proposed the first time in February 2013, when the DoW was already finalized. Therefore, we include SSRS-related activities with T7.2.3 (Requirement traceability) and report on them in O7.2.5 (Requirement management tool choices).

shall be completed by a semi-formal model to describe the functional architecture of the on-board unit." (D2.3, 4.3.4).

There is little relevant information with regard to code generation in this report, except that it makes some implications regarding the software functional model: "A first executable code is produced from the software functional model. This executable code shall be non vital. However, it shall be able to run in real time on a on-board computer. Thus, it shall comply to the standardized interfaces." (D2.3, 4.6.2).

1.3.2 Review, Decision and Resource Allocation

This deliverable is a technical document, intended to outline how a toolchain for openETCS can be created in the most efficient way, while staying true to the principles of the openETCS project and with a minimum of risk. It is a joint creation of the WP7 team with the support of other stakeholders. The resulting deliverable has been produced following the openETCS review process.

Nevertheless, this deliverable contains a number of decisions (Section 4.2). Releasing this document alone does not make the decisions official. For this, a vote is required, according to §3.5 (e) of the PCA, "Taking major decisions about the project and all contributions". Further, a decision according to §3.5 (f) may be required for Decision 6 (use of EFS for V&V).

Last, out of the scope of this document is resource allocation for the individual tasks. Resource allocation in this document could only be prescriptive for WP7 anyway. For other work packages, a recommendation could be given at best. Resource allocation is an internal affair of the individual work packages. This has particular relevance with respect to Decision 10.

1.4 Organization of this Report

This report is organized as follows:

Introduction (Section 1). An executive summary, as well as an overview of the WP7 Task T7.1 activities. It shows how T7.1 fits into openETCS in general and WP7 in particular. It also describes the scope of the results described in this deliverable, making sure the boundary to the secondary toolchain is properly defined.

Results on Means and Tools (Section 2). A short description of the three proposed toolchains. The selection process is described in detail.

Discussion and Results on Tool Platform (Section 3). A description of the proposed tool platform and results of selection is given.

Decision (Section 4). This conclusion sums up the pro and cons of each proposals and gives the decisions made by the consortium.

Detailed Description of the Toolchains (Appendices). The detailled description of each toolchain is given in Appendix A For SysMl and Scade, B for SysML and EFS and C for SysML and B.

1.5 Glossary

API Application Programming Interface

DoW Description of Work. In this document we typically mean the WP7 DoW.

DSL Domain Specific Language

EMF Eclipse Modeling Framework

FIS Functional Interface Specification

HW Hardware

I/O Input/Output

OBU On-Board Unit

PHA Preliminary Hazard Analysis

SIL Safety Integrity Level

SSIL Software Safety Integrity Level

SRS System Requirement Specification

SSHA Sub-System Hazard Analysis

SSRS Sub-System Requirement Specification

SW Software

SWOT Strengths, Weaknesses, Opportunities, Threats

V&V Verification & Validation

2 Results on means and tools for primary toolchain

2.1 Proposed Toolchains

This chapter describes the proposed toolchains and the selection process for finding them.

There were three toolchain proposals in total (Figure 2). These are:

SCADE. A SCADE-based primary toolchain would consist of the two tools Papyrus and SCADE. An integration between the tools already exists, and both tools cover all activities. Specifically, the SysML model can be edited with both, Papyrus and SCADE interchangeably. The biggest advantage is that there would be little additional work necessary to cover the primary toolchain. The biggest drawback of this solution is the fact that SCADE is not open source. However, its artefacts (SysML, XML, Lystre, ASCII text, PDF, C or ADA) are openly defined and can therefore be incorporated into open documents, models, or software. At the lowest level, the code generation, other alternative code generators could be used as well. Within the scope of the openETCS project no development work is planned to adapt SCADE tools to the open

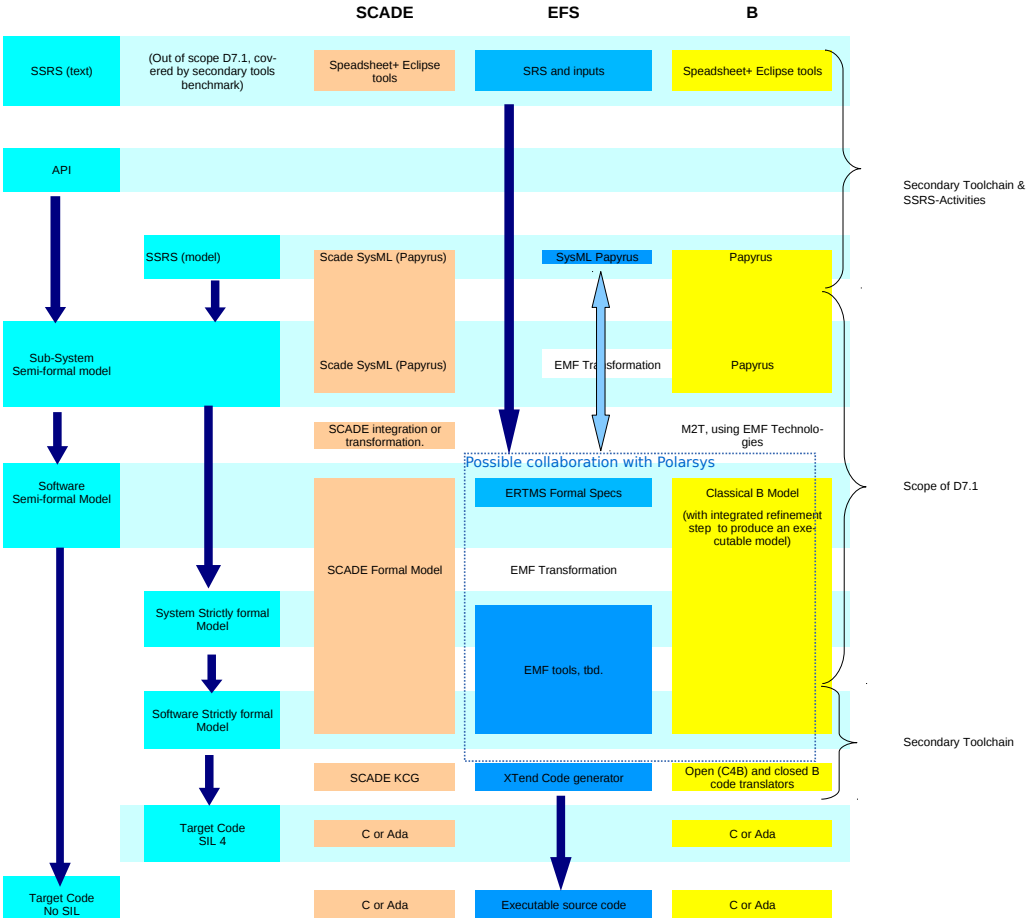


Figure 2. Proposed Toolchains

proofs tools chain, as long as SCADE is not licensed under an OSI certified open source license.

ERTMS Formal Specs (EFS). An EFS-based primary toolchain would mainly consist of the EFS tool itself and optional with additional components from the Eclipse ecosystem, looking at Polarsys for guidance. This toolchain is mainly intended to support the semi-formal modeling and non vital code (no SIL) generation process. (For verification purposes of functional correctness, a second model could be used in parallel.) The biggest advantage of this approach is that it is open source, and that a significant portion of Subset 26 has already modeled with EFS, since it can already be "used as is". The biggest drawback is that EFS is only partly ported to Eclipse, and that it is not clear how laborious the tailoring of the Eclipse-based code generator would be or if any Eclipse-based code generators could be adapted to accommodate these functions. During the course of the project issues are supposed to be collected in order to continuously improve the EFS toolchain and integrate it into Eclipse.

B. In contrast to the previous proposals, this one starts bottom-up, starting with the assumption that code generation from B models is possible and practical. This toolchain proposes working with B on the bottom two layers, but leaves open how these are connected to the Papyrus-based top. The biggest advantage of this approach is that the resulting model will be usable, and that there is a rich existing ecosystem for B, both open source and commercial. The biggest drawback is that there are some blanks to fill in for example to clarify integration of SysML and B and integration to Eclipse, which may require significant development work.

2.2 Selection Process

The selection process consisted of the six steps shown here, with more detail being provided below.

Benchmarking (Done). Project partners were asked to step up and perform a benchmark of the tool of their choice. The proposals were checked against D2.1 (State of the art) to make sure that no important tools were missed (or if so, why). Not all benchmarks were completed, CORE, Why3 and UPPAAL dropped out. Further, after completing the benchmark, GOPPR, GNATprove and Petri Nets were dropped due to the evaluation results. Details in Section 2.2.1.

Assessment (Done). Each Benchmark was assessed by its author and by two additional assessors (in the case of Petri Nets and GNATprove, there was just one assessor). The assessment quantified evaluation criteria, resulted in a report consisting of hundreds of scores for each completed benchmark. Details in Section 2.2.2.

Decision Meeting (Done). A decision meeting took place to eliminate tools and to start looking at possible tool configuration that would form the primary toolchain. During this meeting, Enterprise Architect (SysML) was also eliminated, in favor of the open source alternative Papyrus. Papyrus/SCADE was identified as one promising toolchain. Last, Papyrus had been selected as the tool for the Sub System Semi-formal model. Details in Section 2.2.3.

Composition of Toolchains (Done, this report). With the number of tools reduced significantly and one selected tool (Papyrus), team members were invited to propose concrete toolchains covering the primary toolchain. This resulted in two more proposals, in addition to Papyrus/SCADE. Details in Section 2.2.4.

Documenting the Decision (Done, this report). This deliverable documents the three toolchains, as well as their respective strengths and weaknesses. As has been determined a long time ago[2], we didn't expect a clear single "best" solution. This document will steer the upcoming activities to prevent redundant or unnecessary work. Details in Section 2.2.5.

Final Choice of Toolchain (Due January 2013). Which of the three competing toolchains will eventually be used for openETCS shall be decided six month after D7.1 the latest (as documented in the tool selection process). Note that this may not be one of the three suggested, but could also be a composition of elements of the three toolchains.

2.2.1 Benchmarking

The following thirteen tools had been selected for benchmarking:

SCADE	ERTMSFormalSpecs
SysML with Papyrus	SysML with Enterprise Architect
Classical B with Atelier B	Event-B with Rodin
System C	Petri Nets‡
GOPRR‡	GNATprove‡
UPPAAL†	Why3†
CORE†	

† The evaluation of three tools was stopped prematurely. They are mentioned in [2], but are not evaluated. They dropped out for the following reasons:

CORE. The tool is not open source and difficult to obtain, it seems possible to cover the same task with an open-source approach like SysML.

Why3. Gnat-Prove covers at least the same services and seems more efficient.

UPPAAL. It is a tool dedicated to the verification and validation of time-constraints properties, for example joined with System C. It has been proposed for the benchmark on secondary tools (T7.2).

‡ At the end of the evaluation, three others approaches have been discard from the primary toolchain:

GOPPR. SysML seems a better candidate that offers the same services.

GNATprove. According the results, GNATprove will be evaluated as part of the secondary tools (task T7.2).

Petri Nets. However it is a well-known formal approaches, more recent approaches seems more adapted to the goals of the project.

[2]Tool Selection Process: https://github.com/openETCS/model-evaluation/wiki/Benchmark–to-evaluate-model-and-tools#tool-selection-process

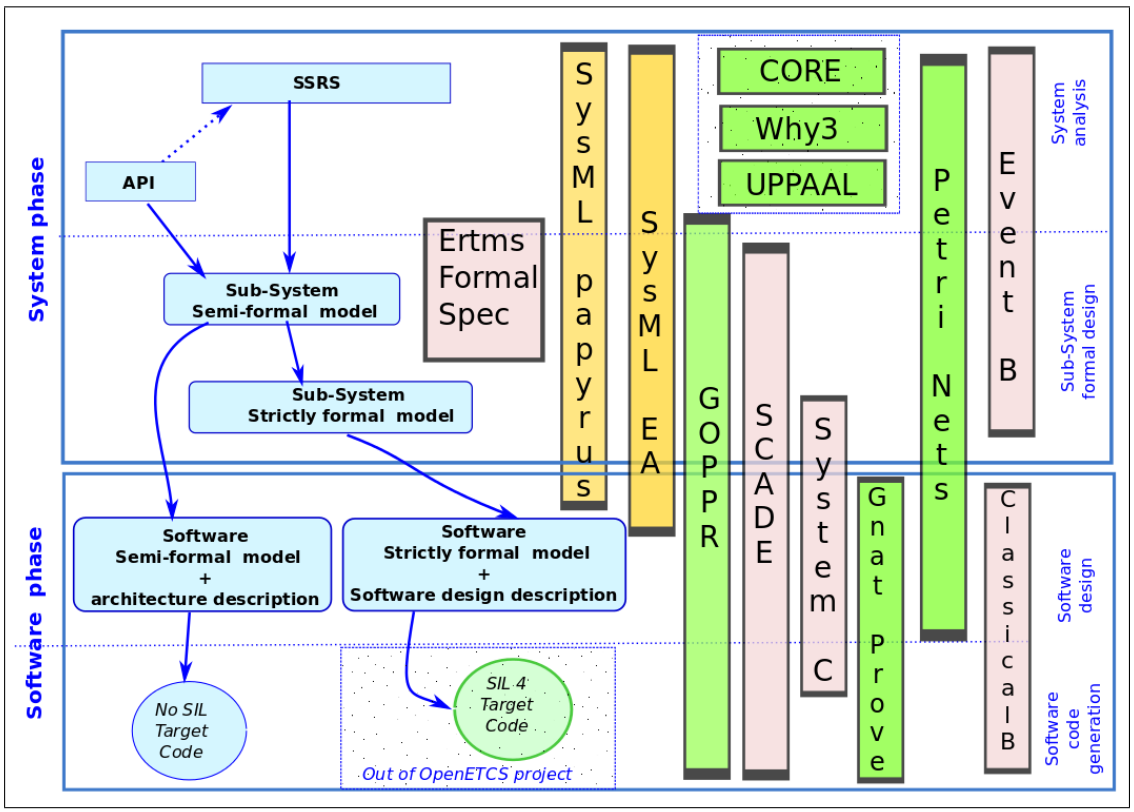


Figure 3. Results of candidates

2.2.2 Assessment

Each Benchmark was assessed by its author and by two additional assessors (in the case of Petri Nets and GNATprove, there was just one assessor). This has been documented in [2], which contains the "raw data", as well as some rudimentary aggregation of the data and some analysis.

The criteria in [2] were derived from WP2 requirements and quantified on scale from 0 to 3. The results were recorded as the sum of the author and the two assessors, resulting in a score from 0 to 9 for each criteria. The benchmarks with only one assessor have been adjusted by interpolating the score, shown in parentheses.

To give an idea of the results, Table 1 shows the aggregated result of the benchmark for process phases. These results must be taken with a grain of salt: This aggregation simply averages all relevant scores, thereby giving all criteria equal weight. This is an unrealistic (and dangerous) assumption. In fact, in the case of the criteria "open source" it created a real problem. As Open Proof is the foundation of openETCS, using a closed-source tool with no open alternative should be a show stopper. But this does not appear in the results of [2].

Further, not all criteria could be quantified easily, resulting in surprising and suspicious results. For instance, the assessments of Papyrus and Enterprise Architect sometimes differed drastically, even in areas where the notation (and not the tool) was concerned. This was not expected, as both tools support the same notation. This means that the results must be inspected carefully, before drawing conclusions.

2.2.3 Decision Meeting

	GOPRR	ERTMSFormalSpecs	SysML with Papyrus	SysML with EA	SCADE	Event-B	Classical B	System C	Petri Nets	GNATprove
System Analysis	5	1	7	**9**	3	**9**	3	2	**6(9)**	2 (3)
Sub-system formal design	**9**	**9**	6	7	**9**	**9**	5	5	**6(9)**	3 (4)
Software design	**9**	0	6	7	**9**	6	**9**	**9**	**6(9)**	**6(9)**
Software code generation	**9**	0	3	3	**9**	3	**9**	6	2 (3)	**6(9)**

Table 1. Use of the approaches during process phases

On July 4th, a WP7 workshop took place with the objective of choosing suitable tools for the toolchain. To ease the process, the results from [2] were condensed into Figure 3. The vertical stripes represent the individual tools. The length and position of the stripe is determined by Table 1. The bar only covers area with a score of 6 or higher.

2.2.3.1 SysML

Using the available data as the foundation, the objective was to narrow the choices down as much as possible. One obvious redundancy was the availability of two SysML tools, Papyrus and Enterprise Architect. After discussion of pros and cons of each, the partners agreed that Papyrus covers better the objectives of the project, especially the open-source requirement.

Further, by vote, all the partners agree on the use Papyrus/SysML to cover the highest level of the OpenETCS V-cycle.

2.2.3.2 Short List

Due to the evaluation and discussion during the decision meeting, the partners agreed on a short-list of six approaches. These are shown in red in Figure 4. and include the following:

- SCADE
- SysML with Papyrus
- Classical B with Atelier B
- ERTMSFormalSpecs
- System C
- Event-B with Rodin

2.2.4 Composition of Toolchains

One toolchain was already suggested during the Paris meeting, namely Papyrus and SCADE. Nevertheless, partners had the chance to propose additional toolchains using the tools from the shortlist. It was necessary to find alternatives, as one severe weakness of the Papyrus/SCADE solution had already been pointed out in Paris: By not being open source, this solution would miss one of the main objectives of openETCS.

Two more toolchains have been proposed, resulting in three toolchains in total. These have been documented by their respective owners in the appendices.

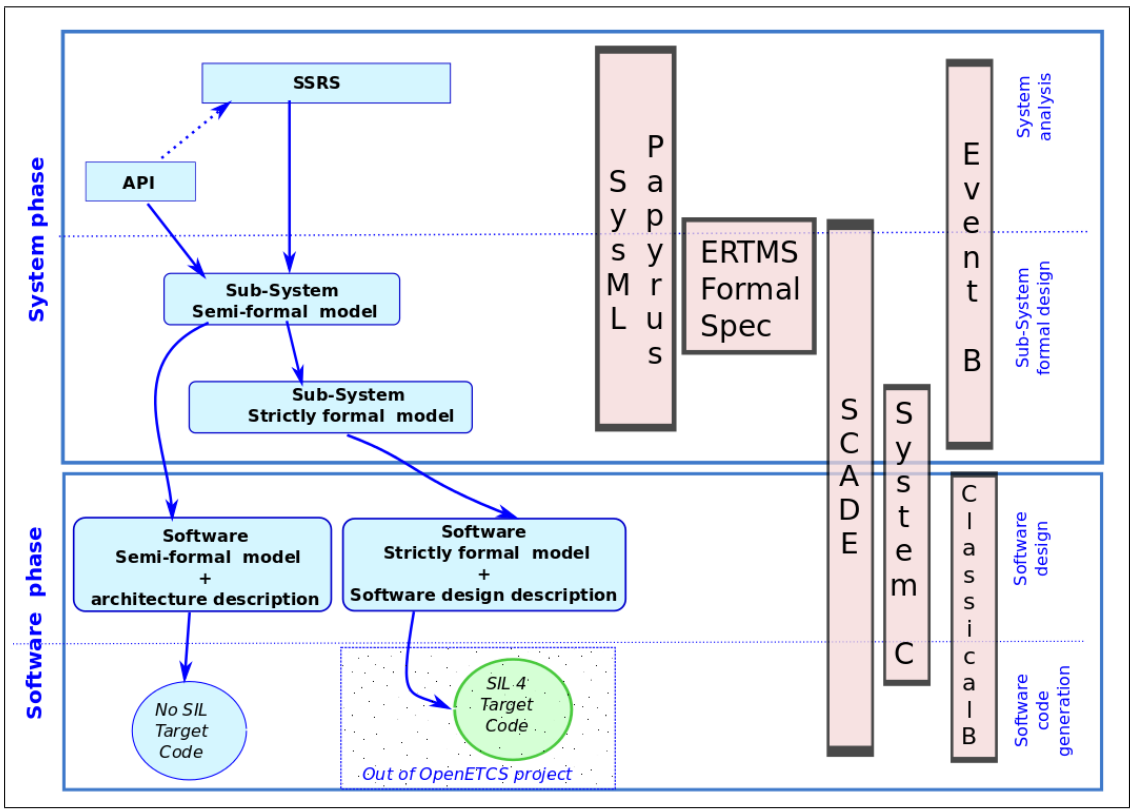


Figure 4. Short list

2.2.5 Documenting the Decision

What has been documented so far is a promising foundation for an openETCS primary toolchain. However, it is not clear on how to proceed from here, as there are multiple competing avenues. Resources in the project are thin and should be employed wisely. Therefore, Section 4 contains an elaborate analysis with clear decisions that will guide the activities of the next six month, ensuring that we will choose the best option for openETCS while minimizing risk.

3 Results on Tool Platform

The tool platform should provide mechanisms to integrate various tools. The tool platform is not the same as the primary nor secondary tools, nor the toolchain. It is the support for the toolchain implementation, it shall help to integrate the tools into one seamless toolchain. The evaluation has focused on the integration capabilities of the tool platform.

3.1 Initial List of Candidates

- Eclipse
- TOPCASED/Polarsys
- CAESAR RTP
- Mono/.NET
- SCADE

After a first round, Mono/.NET and SCADE were discarded because they do not comply to our tool platform definition. CESAR RTP was also discarded, the maturity of this project is not yet usable. Finally, **Eclipse with the modeling framework (EMF)** has been chosen as a tool platform. The possibility to use Polarsys and take some part of the TOPCASED toolchain, as well as which version of Eclipse and EMF to choose, are discussed in the next sections.

Eclipse can also integrate other frameworks. It has also been decided that any framework added to the Eclipse platform within the OpenETCS toolchain should be documented (version, usage, ...) and clearly justified.

3.2 Eclipse

Eclipse is an open source tool platform originally developed by IBM. It has been explicitly designed as an extensible platform to enable different tools to exchange data and share common functionality. Additionally, Eclipse is a rich open source ecosystem with a variety of frameworks for different purposes, such as versioning, code generation, language support and many more. The Eclipse Modeling Framework (EMF) as a top level project bundles all modeling frameworks at Eclipse. Additionally, it technically provides a common data format for modeling purposes. Originally it has implemented the Meta-Object Facility (MOF), an OMG standard. Later it has been reduced to essential MOF (eMOF), also an OMG standard. EMF provides a model-driven approach for developing modeling languages. It allows to define custom meta-models and generate code from them. Additionally, it provides common features such as command-based editing and XMI serialization for generated models. In the following we show how Eclipse and EMF aligns with the openETCS requirements.

Open Source

All Eclipse core components, including EMF, are open source and under the Eclipse Public licenses, which allows for commercial use and is compatible to the EUPL[3]. The Eclipse Foundation and the Eclipse Development process assure the management of the intellectual properties for all Eclipse projects. Additionally, all Eclipse projects follow a common infrastructure and process allowing external partners to contribute and maintain projects.

Long-Term Maintenance

The Eclipse Foundation also provides infrastructure and a process for long-term maintenance for all Eclipse projects. It enables users of a technology to contract service providers to maintain current and older versions of this technology. These service providers do not necessarily have to be committers on the original projects.

Portability

Eclipse itself is implemented in Java and therefore portable to all major operating systems. The underlying UI technology SWT is implemented for all major and even most uncommon window kits. As SWT uses native widgets, the performance of the UI is close to native applications. The Eclipse Java IDE has a user based of several million developers, which ensures that the platform runs stable on the supported platforms. Since version 4.2, EMF is part of the core platform. However, EMF does not contain any OS specific components and is therefore highly portable.

Tools Interoperability

The Eclipse Platform has been explicitly designed to enable various tools of the software life cycle to collaborate. It provides mechanisms, such as a service oriented architecture and extension points to enable the communication between different parts of a tool chain. EMF is well-suited as a common data-format. The collaboration of a large number of tools is shown and validated in the various Eclipse packages, which are released in the yearly release train.

Modularity

Eclipse is based on OSGi, a standard for modularization of Java applications. The Eclipse OSGi runtime Equinox is the reference implementation of OSGi. OSGi enables to modularize a system, in this case the toolchain. Additionally, it allows to specify the API of modules and the dependencies between them. Further, the existing platform provides many possibilities to be extended by new features. The extensibility and OSGi as an underlying technology allow fully customizing the Eclipse Platform. Existing pieces and frameworks can be added to a toolchain, new parts can be developed.

Framework Support

Over the last ten years, a rich ecosystem of frameworks has developed around the Eclipse Platform. All these frameworks are developed under the EPL and checked for IP cleanliness. Eclipse frameworks cover all different kinds of purposes, with a strong focus in support for tool development and modeling. Modeling technologies are almost all compatible with EMF as a common data format. Technologies provided by Eclipse projects include:

1. Textual Modeling and DSL (e.g. Xtext)

[3]For more details on EUPL licence, see `https://joinup.ec.europa.eu/software/page/eupl/eupl-compatible-open-source-licences`

2. Language Support (e.g. CDT, JDT)
3. Source Code Versioning Clients (e.g. Egit, Subclipse, Subversion)
4. Model Repositories and Versioning (e.g. EMFStore, CDO, EMFCompare, EMF Diff/merge)
5. Code Generation (e.g. Xpand, Xtend)
6. Model Transformation (e.g. ATL, QVT)
7. Model Development Tools (e.g. Papyrus, OCL, RMF, Sphinx, eTrice)
8. Graphical Modeling (e.g. Graphiti, GMF)
9. User Interfaces (e.g. JFace, Databinding, EMF Client Platform, EEF)
10. ALM Tooling (e.g. RMF/ProR, Mylyn)

3.3 TOPCASED and Polarsys

TOPCASED is a tool for systems engineering, based on Eclipse and various Eclipse projects. Polarsys is a project concerned with the long term support of the TOPCASED toolchain. There is an overlap between TOPCASED and the openETCS toolchain. There is also an overlap between the objectives of openETCS and Polarsys:

TOPCASED and openETCS toolchain. Both, TOPCASED and the openETCS toolchain are based on Eclipse. Further, the openETCS toolchain will definitely use Papyrus, which is also part of TOPCASED. And last, both are concerned with covering all aspects of the V-Model, although for different domains (aviation vs. rail).

Polarsys and openETCS. The objectives of Polarsys and openETCS overlap significantly as well: Both are concerned with tools in a safety-critical domain, requiring tool qualification, etc. They are also concerned with long term support through open source.

TOPCASED is in Maintenance mode now and only relevant in terms of “learning from other Projects”. Artifacts are in general not valid/maintained any more out of this toolbox. Moreover, while the state of the art document mentions TOPCASED [8], it was not evaluated as a whole. Merely the Papyrus component of TOPCASED was evaluated, but a newer version than the one used by TOPCASED.

PolarSys is an excellent option to join forces. First of all, Papyrus is part of the project and can be jointly improved. Moreover, the current toolset does not give all the elements for the chain we urgently need. But it is a place where we could get a nice harbor of collaboration. Furthermore, the general goals of PolarSys and openETCS are in good harmony. So we will reach out to the Polarsys community to see if OpenETCS toolchain may be merge with Polarsys long term support.

4 Decisions

As anticipated, there is not one single tool choice done by WP7 partners. This has the advantage of reducing risk (if a tool does not work out), but the disadvantage of potentially wasting resources and being unfocused. The objective of this chapter is to summarize results of analyses (see Section 4.1) and the decisions and to propose a work plan that leverages the advantage of having multiple tools, while reducing the risks resulting from this. (see Section 4.2. However, the choice of the tool platform was easy and unanimous.

4.1 SWOT Analysis

By looking a the strengths, weaknesses, opportunities and threats (SWOT) of each toolchain, we will get a qualitative impression on what we could gain with each solution, and what the risks are.

4.1.1 SCADE SWOT Analysis

Scade delivers all the required features, but is closed source.

4.1.1.1 Strengths (SCADE)

The biggest strength of SCADE by far is that it works “out of the box”, barely any tailoring is required. SCADE has been developed for systems engineering, and this is exactly the right field of application. Further, a Papyrus integration is already available, so little work has to be done here. Another strength is the fact that some of the secondary tool activities are covered by SCADE as well.

4.1.1.2 Weaknesses (SCADE)

The biggest weakness of SCADE is a show stopper: SCADE is not open source, and as no open source alternative exists, openETCS would miss its Open Proofs objective.

4.1.1.3 Opportunities (SCADE)

Using SCADE would doubtless increase the chances of success of the modeling activities. Thus, SCADE is an excellent backup plan. By nominating SCADE as a backup, we would ensure damage control: A successful model, even if not created with open tools is preferable to no model at all.

There is another opportunity: by dangling the chance to adapt SCADE and potentially opening a large market segment, Esterel (manufacturer of SCADE) may decide to open SCADE — at least enough for our purposes.

4.1.1.4 Threats (SCADE)

There is the real threat that Esterel is encouraging us to adapt SCADE under the premise of opening parts of SCADE to be compliant with Open Proofs. If such discussions would breakdown, after modeling has already started, we’d have a problem.

4.1.2 ERTMS Formal Specs SWOT Analysis

A significant portion of the ETCS specification has already been modelled with EFS, albeit with a semi-formal language.

4.1.2.1 Strengths (EFS)

EFS is open source. Even better, a significant portion of the ETCS specification has already been modeled using the tool. The creator of the tool (ERTMS Formal Specs) is available in the project and has project resources for WP7, which should result in fast turnaround during development.

It has already been proven that all features of the ETCS specification can be modeled.

EFS has been developed as a commercial tool and is based on real-world needs in the rail industry.

4.1.2.2 Weaknesses (EFS)

EFS has originally been written using the .NET platform. Even though a prototype based on Eclipse EMF exists, a significant amount of work is required to make it truly user friendly. However, it should be possible to work during a transition phase with the old tool.

As the notation of EFS is more of a domain-specific language (DSL), a debate has been going on whether EFS is “formal enough”. This is not a big problem, as the model could be extended with fully-formal models in relevant places. A bigger question is how the integration of the various models would be realized. There won’t be a clear answer on that, until we try it out.

Last, the “lower part” of the toolchain is citing technologies that need a significant investment of energy before they can be used. For instance, Xtend is a programming language, which is not doing anything domain-specific.

4.1.2.3 Opportunities (EFS)

The main opportunity is to safe time and resources, as a significant portion of the ETCS specification has already been modeled. Another is the certainty that a commercial partner will be engaged in the ongoing activities, even after the end of openETCS.

4.1.2.4 Threats (EFS)

The continuation of the toolchain, as shown in Figure B1, leave some questions open. Compare that to the much more concise description of the B-approach in Figure C1. Due to the ambiguity there is a significant risk that the model integration won’t work as shown.

4.1.3 B SWOT Analysis

B has industry strength and the ecosystem includes open tools, but not all aspects of the ETCS may be representable, and the learning curve is steep.

4.1.3.1 Strengths (B)

B is proven in the rail industry, where it has been deployed successfully. There is also a strong body of academic research that can be taken advantage of.

There is a decent amount of tooling already available, both open source and commercial. However, an almost complete open toolchain has been suggested in Table C1, with the Atelier B type checker being the only exception (see Weaknesses below).

There is B-related expertise in the consortium, ensuring that questions can be answered and that there is a commercial incentive.

4.1.3.2 Weaknesses (B)

Atelier B is not Eclipse-based, and Appendix C points out this shortcoming. On the positive side, it is available on all relevant platforms (Windows, Mac, Linux).

There is also the Atelier B type checker, which is not open source. Finding an open replacement for this relatively small component would be one mandatory activity.

While B is well-suited for modelling state-based systems, it is more difficult to model real-time behaviour.

4.1.3.3 Opportunities (B)

B could be the sweet spot between using a commercially proven approach (like SCADE), while still residing in the open source realm (like TOPCASED). And as there are more options available, both open and closed, the risk is lower.

4.1.3.4 Threats (B)

Acceptance may be the biggest problem, as B is a "hard core" formal notation, which is considered hard to read. We must be prepared to train the users and ensure that they accept it beforehand.

4.2 Decisions

In the following, we will document a number of decisions that follow from our analysis and that will guide the activities until the end of 2013.

The tools covered here must allow working with the four models shown in Figure 1.

During the review process, a number of issues were discussed, which are available in the toolchain issue tracker (identified by the tag "D7.1 Review"). A number of core ideas have been identified from this, which are documented on the wiki[4]. These ideas are referred to in the following by their IDs.

4.2.1 Decision on the Tool Platform

There was no ambiguity with respect to the platform choice.

Decision 1

By vote in Paris on July 4th, 2013, all the partners agree on the use of **Eclipse** as tool platform.

[4] `https://github.com/openETCS/model-evaluation/wiki/D7.1-review`

Which version of Eclipse[5] will be used is up to the implementing team T7.3.

4.2.2 Decisions on the Modeling Tool

The vote for Papyrus-based SysML had already been done in Paris, but later it was clarified that the SysML model must be editable (core idea O-7):

Decision 2

By vote in Paris on July 4th, 2013, all the partners agree on the use Papyrus/SysML to cover the highest level of the OpenETCS V-cycle. Later it was clarified that it will be an original or bidirectional synchronized (but not a derived) artifact.

All proposed toolchains will use SysML with Papyrus. To keep things as flexible as possible, it would be desirable to use SysML in exactly the same way for all approaches. The B team suggested to create modeling guidelines, and to build a validator for validating the SysML model accordingly. It is recommended to use the last release of Papyrus and associated version of SysML language[6].

Decision 3

With input from WP2 and WP3, a WP7 will develop a validator for Papyrus-based SysML.

During the review meeting, consensus was reached that it would be possible for WP3 to start SysML modeling, without knowing which other tools would complement the toolchain (core idea O-6). This is an important premise, upon which the rests of the decision rest, and which must be confirmed by the WP3 stakeholders. To a degree, this is in conflict with core idea S-4, but this is softened by Decision 7.

Decision 4

As the first toolchain release, WP7 will provide at a minimum a Papyrus SysML environment to WP3, under the assumption that this is sufficient for WP3 to start modeling, until the final decision has been made (see Decision 5).

Nevertheless, The rest of the tool chain must be decided upon eventually. It is unambiguous when this has to happen (core idea O-1):

Decision 5

A final decision on the primary toolchain must be made by the end of January 2014. After this point, WP7 resources must not be spread between competing tools.

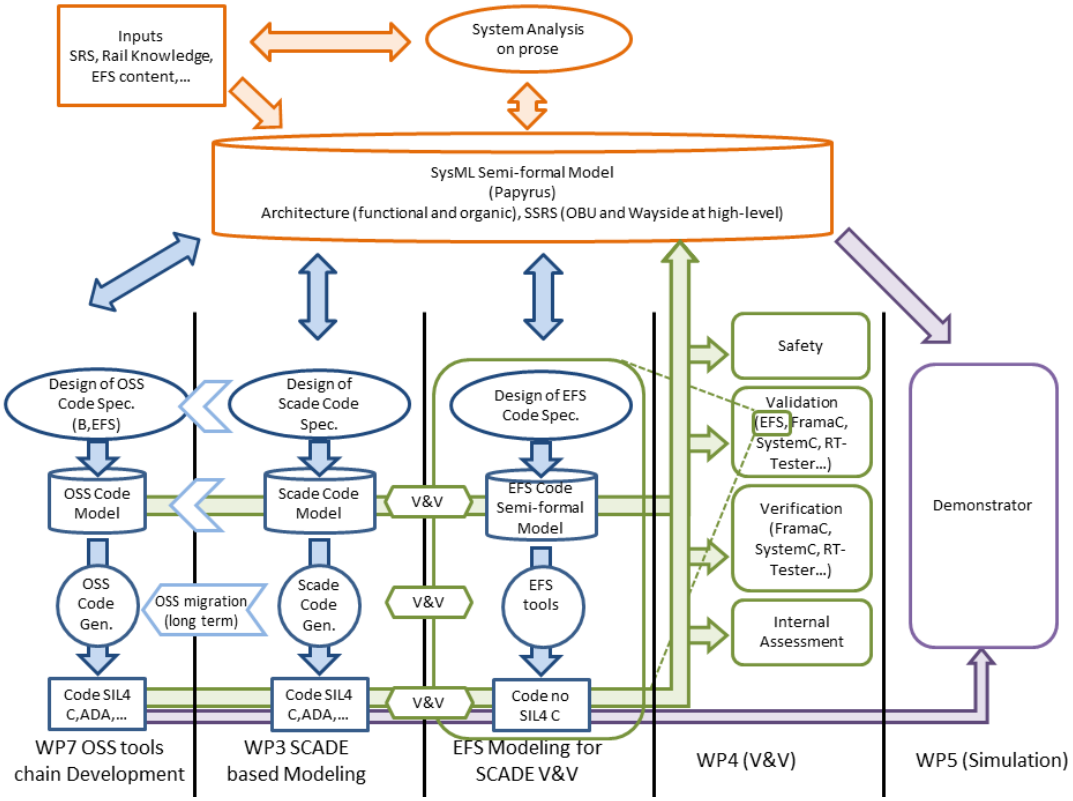


Figure 5. Proposal for putting the various tools to use.

A toolchain proposal had been made by Matthieu Perin, shown in Figure 5. This proposal was generally met with agreement (discussed in issue #144, see core idea E-3).

In particular, this approach is interesting with the respect to EFS, as its main objective would become supporting V&V activities. However, should there be a problem with the primary toolchain, this would still allow EFS to be used as the main model. This approach makes EFS complementary (rather than competing) to the primary toolchain and allows openETCS to take advantage of the existing modeling that has already been done with EFS.

Decision 6

EFS activities will be coordinated with WP4, to support V&V activities (as these are modeling activities, they still belong in WP3). This issue must be raised and resolved with the PCC.

Further, Matthieu proposes to use SCADE to be the primary toolchain. This is based on core idea S-4, that Scade is the only viable option to get started NOW. Note that this point of view is dominating, but by no means universal. There are proponents for B and EFS, who will still be able to influence this decision, as outlined by Decision 5.

[5]The last release is Kepler 4.3, launched the 26 of June 2013.

[6]The last release is Papyrus 0.10.0 launched 26 of June 2013 and based on Eclipse Kepler 4.3. It support completely SysML 1.1 and largely SysML 1.2.

This also means that Decision 3 must be performed in a way to take the constraints of the SCADE Papyrus model into account.

Decision 7

Unless new evidence is provided in agreement with Decision 5, SCADE will be considered the foundation for the primary toolchain. In that case, a feasible migration from what had been done with SCADE is essential.

SCADE two major drawbacks: (1) it is not open source, and (2) it is very expensive (core idea S-3). Figure 5 addresses the first issue, which is also recorded in core idea S-1, by proposing an OSS migration to a B or EFS-based toolchain. In fact, as outlined in Decision 7, this migration may happen much sooner, if evidence is presented.

Decision 8

Work on the toolchain must always take the objective of an OSS migration into account, e.g. by standardizing interfaces between tools. It is acknowledged that such a migration may not be feasible within the timeframe of the openETCS project. However, by the end of the project, feasibility of a migration must be demonstrated (e.g. with a prototype or case study).

The second issue can only be resolved in collaboration with Esterel, the manufacturer of SCADE. Klaus-Rüdiger Hase expressed confidence in finding a solution for all parties, after the initial negotiations with Esterel. To make sure that we won't have a problem in this regard, we formulate the following "nuclear option" and will make Esterel aware of it:

Decision 9

All openETCS project partners must be made aware of the need for acquiring a SCADE license (depending on their activities). If a partner feels that this is not achievable, this must be escalated to the project office by **November 15, 2013**. The project office will assist in finding a solution. If no solution has been found by January 31, 2014 for all partners who escalated, then SCADE will be abandoned for anything on the critical path of the toolchain.

Last, there are proponents for EFS and B. While work on EFS will continue, as described in Decision 6, we will state explicitly that the B team may continue to investigate the possibilities of its use, in the spirit of a meritocracy.

Outside help for this task may be available, as Polarsys (an Eclipse Industry Working Group) has similar objectives. The team is strongly advised to coordinate with them. This is reflected in core idea O-5.

Decision 10

According to the spirit of an open proofs project, team members are permitted to continue evaluating B, even with the objective of contradicting Decision 7. However, if unsuccessful by the deadline set by Decision 5, they must refocus either by contributing elsewhere, or by focusing on the transition to OSS, as outlined in Figure 5[7]. The team is strongly encouraged to coordinate with Polarsys.

4.3 Recommendations for WP3 Modeling

We can make decisions for WP7, but can only articulate recommendations for WP3. Making these will hopefully clarify the intentions behind our decisions even more.

While the decisions document that for now, SCADE and Papyurus will be the foundation for the primary tool chain, we strongly recommend to focus on Papyrus and to do as little work with the SCADE tools. There are still many discussions ahead, also with respect to the secondary tooling. Thus, the longer the decision can be delayed, the better. It will also allow the D2.4 team to provide a development method.

4.4 Conclusion

Reaching the decisions documented here was the result of the constructive collaboration of a large number of partners. We believe that we decided on an approach that will allow WP3 and WP4 to confidently pursue their activities (modeling and V&V, respectively), while still leaving room to adjust course within the next six months. The decisions lay the groundwork for building an open proofs toolchain. However, should we not manage to achieve this ambitious goal, this will not jeopardize the project.

The previous section 4.2 gives the actual decisions taken by WP7 and project partners. However, decisions or points of view have been given by the leaders of other workpackages and are summed up in the sequel.

4.4.1 WP3 point of view

Point of view of WP3 leader, taken from issue #109):

> Indeed, ALSTOM, as modeling WP leader, needs now to organize WP3 kick-off meeting and ressources working within a clear framework and objective. With D7.1 conclusion as it is now, WP3 ressources are working now in the tools they want to work on without clear strategy nore objective. Therefore, ALSTOM proposed following D7.1 conclusions to be:
>
> 1. Despite the fact it is not fully open tools, “SYSML / SCADE” is the baseline primary tools chain to be used for any modeling activity within the frame of the OpenETCS project unless other agreement and.or decision not late than January 2014.

[7] This decision assumes that the WP leader has managerial authority over the work package’s resources (and consequently, that these activities are coordinated with WP leadership). If it turns out that this is not the case, then this aspect of the decision will be void. This is currently investigated and documented in `https://github.com/openETCS/governance/issues/60`.

2. In order to allow availability of another complete full OpenETCS Tools chain, complementary analysis and work will be carried out on the 2 other options “SYSML/EFS/Eclipse Polarys” and “SYSML / Classical B” for final decision on "OpenETCS" Tools chain not late than January 2014

Such conclusion is likely to avoid dispersion of WP3 ressources that lead to impossibility to manage modeling WP while keeping intact the possibility for the other candidate tools chain to be adopted if confirmed as complete and usable as the only today’s available fitted for purpose “SYSML / SCADE” solution.

4.4.2 WP4 point of view

Some decisions have been made by the WP4 partners regarding VnV and safety activities. these decision have been announced during the decision in Paris on July 4th, 2013:

Decision 11

WP4 is going to consider the artifacts of "SysML+ Scade" toolchain for the first round of verification and validation launched in July 2013.

Decision 12

For the following rounds, starting in February 2014, WP4 will adapt the verification and validation activities to the models and code provides by WP3.

Appendix A: SysML and SCADE

A.1 Description of the approach

Figure A1 illustrates the most important components and operational relationships of a system and software modeling toolchain based on SysML, Papyrus, SCADE and Eclipse. All components and links shown with solid lines are available, while the dashed ones are intended to be implemented within the openETCS project.

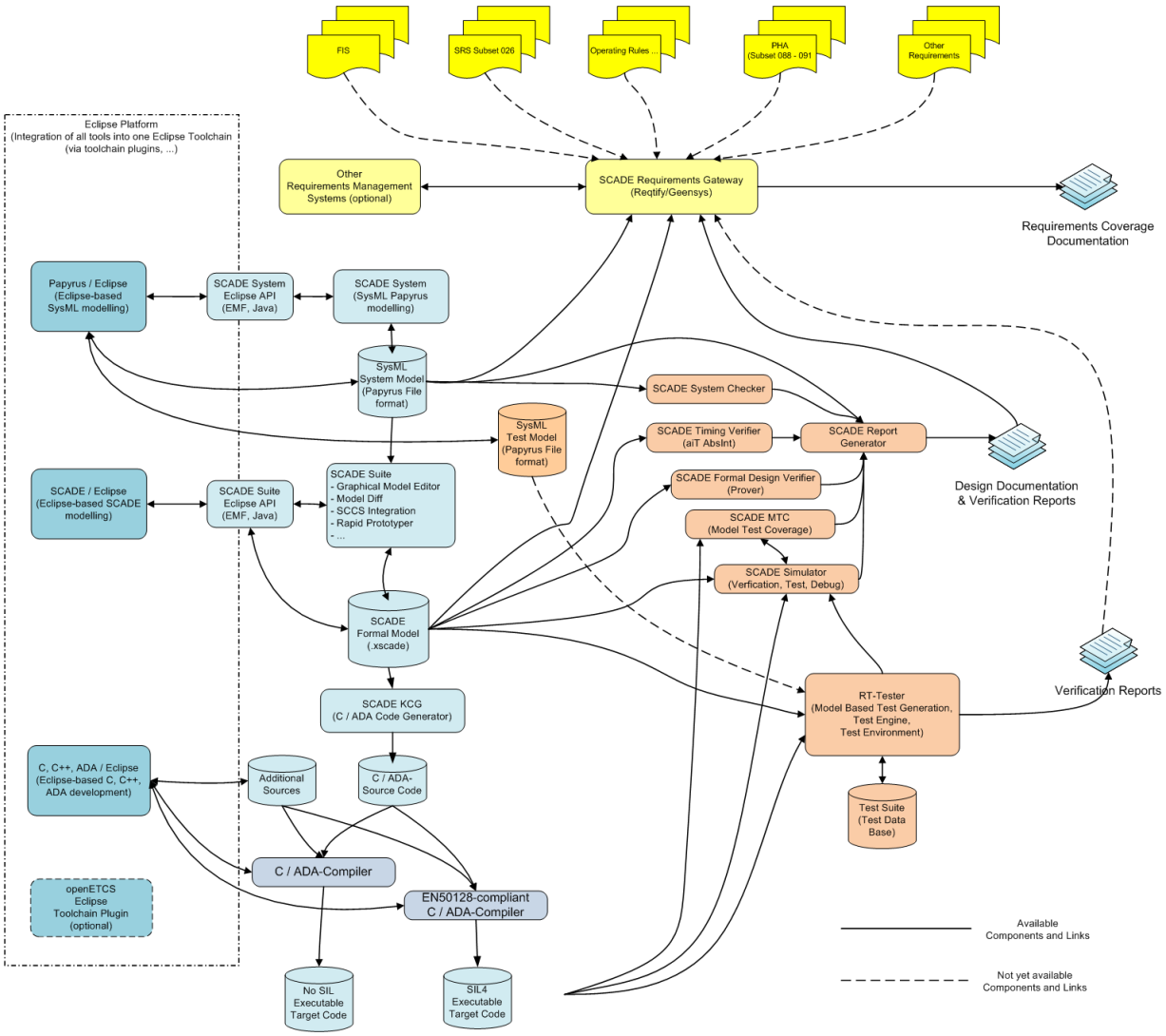


Figure A1. SysML SCADE Toolchain

The diagram colors are chosen related to the colors in Figure 1:

- Requirements and requirements management components in yellow
- "Blue" openETCS design process (see Figure 1) elements in light and dark blue
- Eclipse is painted dark blue

- Verification elements in red

Within the following paragraphs and subsections a short description of this approach will be given by walking through the tool chain and the design process.

A.1.1 Requirements management

The SCADE Requirements Management Gateway is based on Reqtify from Geensoft / Dassault Systems and serves to collect and link all requirements from the openETCS input documents and related objects as design and verification documents, model and source code artifacts, test cases, test protocols etc. It supports impact analyses and generates requirements traceability and requirements coverage reports. If needed for the openETCS process, it can be complemented with other requirement management systems and already comes with interfaces to these. Because ProR bases upon the ReqIF file format, and one working principle of Reqtify is to access any type of requirement files via configurable import/export filters, an intergration with ProR is achieveable with little effort.

A.1.2 Semi-formal System and Subsystem Modeling with SCADE System / Papyrus

SCADE System is an integration of Papyrus into the SCADE IDE intended for SysML system modeling. It allows to modelize the interactions and hierarchical dependencies between the various parts of a complex system through design elements representing functions, data and interfaces.

The idea is to model system structures, data types / data dictionaries, inputs, outputs, interfaces and relationships between blocks with SysML and transfer it to native SCADE for behavioral modeling automatically. Since Papyrus and SCADE System are using the same file formats, there is no prevention of using all SysML capabilities that Papyrus supports, but in this case without automatic transfer to native SCADE.

SCADE System supports SysML Block Definition Diagrams (BDD) and Internal Block Diagrams (IBD).

More details about the relationship between Papyrus and SCADE System:

1. SCADE System 2.x incorporates Papyrus 0.9, but SCADE System is more than Papyrus, as outlined in the following list. SCADE System 3.x (Mar 2014) will be based on Papyrus 0.10.
2. SCADE System enhances Papyrus with functionalities on top:
   - Report Generator: Generation of design documents out of the SysML model
   - Model Check: user expandable checker on SysML models (TCL rule checking in addition to the OCL based rule checking as provided by Papyrus, . . .)
   - Model Diff: Semantic comparison of models in addition to the Papyrus Diff
   - Interface to requirements management (Reqtify)
   - Synchronization with SCADE Suite: Mainly blocks and functions with their structure, interfaces, flowports and data types can be transferred to SCADE Suite.
3. The idea of SCADE System is to ease the work for system and software architects. SCADE Systems users don't need so deep knowledge and experience of UML, SysML and . . . profiles

as native Papyrus requires, so that architects or rail engineers, that are not UML experts, are able to work with. Therefore, SCADE System tailors Papyrus in several aspects:

- Cleaned up views and user interface and less chances of doing things wrong compared with native Papyrus.
- Support for designing blocks (BDD, IBD), relationships and data flows/interfaces between them (as Papyrus).
- Support for data types, data dictionaries (as Papyrus).
- Allocation of functions (as Papyrus).

4. Actually, SCADE System does not support behavior modeling, but has it on the road map for the next year.
5. SCADE System uses the same file formats as Papyrus, so that SCADE System and Papyrus files are exchangeable in both directions. SCADE System simply hides SysML artifacts it does not support. This gives the opportunity for:
   - Using SCADE System for non-UML/SysML experts (architects and rail engineers)
   - Using Papyrus for UML/SysML experts software experts
6. For integration with Eclipse, SCADE System (as well as SCADE Suite) comes with an Eclipse EMF API including the enhancements on top of Papyrus

With the exception of the synchronization with SCADE Suite, the mentioned easements and enhancements may also be achievable with Papyrus by tailoring and added functionality. For openETCS, behavioral modeling seems to be necessary for a rather complete model on SysML level. Therefore, SCADE System, because ready to use right now, could be chosen for architectural modeling and SSRS matters at the beginning and then continued with Papyrus, when a tailored Papyrus variant becomes available.

A.1.3 Formal Modeling with SCADE Suite

SCADE Suite integrates all modeling, verification and supporting SCADE tools under the roof of the SCADE IDE. The components relevant for descending part of the development "‘V"’ process are

- SCADE Suite Editor (Graphical and textual modeling)
- SCADE Requirements Gateway Integration (Linking of model artifacts with requirements)
- SCADE Model Check (model syntax check)
- SCADE Model Diff (model comparison)
- SCADE Simulator (graphical debugging, simulation and testing)
- SCADE Rapid Prototyper (quick control and display elements for rapid prototyping, optional)
- SCADE Code Generator KCG (C / ADA code generation)
- SCADE Reporter ((Design) report generator)

The most important tools for modeling are editor and code generator. The others mentioned are mainly verification tools, but very useful and practically indispensable for agile development.

At least, to cover all elements of the "blue" design process in figure 1 a C / C++ / ADA compiler is required. For building not safety-relevant executables any C-Compiler (gnu c, ...) is suitable, for safety relevant executables the compiler must be compliant with EN50128.

A.1.4 Model Verification

The verification of openETCS SCADE models can be performed with the "'red"' components shown in diagram A1. Most of them are part of SCADE System or SCADE Suite:

- SCADE Simulator: The SCADE Simulator should be used in an agile iterative development process for a steady accompanying verification of the modeling work. Simulator test scripts allow executing verification suites for the models automatically. Via its automation and co-simulation interface it is able to be integrated in the openETCS tool chain.
- SCADE Model Test Coverage MTC: The MTC serves to determine structural model test coverage while executing test scenarios. Instead of measuring code coverage on the generated code, it works on the model structure directly. The MTC tool is automatable.
- SCADE Design Verifier: The verifier performs formal proving and bases upon a model checker from from Prover Technology AB.
- SCADE Timing Verifier: Execution timing verification based on aiT from AbsInt.
- SCADE Report Generator: Generation of design reports for SCADE Suite and SCADE System model as well as for verification results.
- RT-Tester: Test engine and environment with model based test case generation and interface to SCADE, see openETCS contributions of the University of Bremen. The ability to derive test cases from a test model complements the verification tool chain with model based testing capabilities.

A.2 Description of the approach for OpenETCS design process

The approach as specified in the previous subsections (Chapt. 1.3) covers all elements of the "blue" design process (see figure 1) by using the SCADE tool chain including requirements management, semi-formal system and formal subsystem/software modeling, code and executable generation. An Eclipse integration is provided.

A.3 Integration of the approach with SysML/Papyrus

Because SCADE System bases on Papyrus mounted into the SCADE IDE and uses native Papyrus file formats, a seamless integration with SysML / Papyrus is available. Models can be edited with both, Papyrus and SCADE System and therefore exchanged in both directions.

Behavioral modeling has to be done with Papyrus until supported by SCADE System as announced for the near future.

A thrilling question for the openETCS process might be, if and - if yes - which of the artifacts on system level should be modeled with SysML, that can not be transferred to native SCADE automatically.

A.4 Integration of the approach with Eclipse

All SCADE tools can be run and controlled via command line and/or via automation interfaces.

SCADE System (SysML modeling) and SCADE Suite (SCADE modeling) already come with Eclipse API plugins based on EMF. These enable to access (read and modify) the model project information, meta and model data from within Eclipse. The plugins additionally display the model structure, but they don't show the model graphics in Eclipse.

If graphical modeling should be done within Eclipse, this has to be implemented by openETCS. It is in doubt, if the effort for this activity would be applicable; without any effort, the SCADE editor should be used instead.

Nevertheless, the provided Eclipse integration is worthwhile to supply all openETCS users, that are not directly working on the SCADE models, with an integrated Eclipse tool chain. The idea of such an integration is to have one build tool chain, that starts and runs an openETCS executable build process with one button click beginning from all (heterogeneous) sources and performing all necessary model transformations, code and executable generation. This could be achieved with an "'openETCS Eclipse Tool Chain Plugin"', implemented as part of the openETCS project with the goals ease-of-use and convenience.

In summary, an Eclipse integration is available. An optional "openETCS Eclipse Tool Chain Plugin" could improve the convenience for openETCS tool chain users.

A.5 Benefits versus OpenETCS requirements

The most important benefits of the SysML/SCADE approach are:

- seamless integration,
- completeness,
- maturity,
- qualification for safety critical development,
- productivity
- availability just now.

The SysML/SCADE approach covers almost all aspects of the openETCS process and lets expect to fill gaps with manageable effort.

Therefore, the modeling work for openETCS can begin immediately.

Additionally, the SCADE language covers the capabilities of the ERTMSFormalSpec language, so that ERTMSFormalSpecs models could be transferred to SCADE automatically. Nevertheless, this would require a model transformator, that does not exist actually.

A.6 Shortcomings versus OpenETCS requirements

The SysML/SCADE approach has one drawback: the tools are mainly not open source. These facts may help to better come to terms with it:

- The SCADE language is documented and very regular.
- The file formats are documented and easy to understand.

Therefore, the SysML/SCADE approach is open for bidirectional transformations to other modeling languages.

A.7 On going work for openETCS project

The availability of the nearly complete SysML/SCADE tool chain gives the freedom to focus on few items to clarify:

- Since the tool chain offers several capabilities and options, it has to be determined how these shall be used within the openETCS process.
- A justifiable balance has to be found between semi-formal modeling in SysML and formal modeling in SCADE.
- Some aspects of the RT-Tester integration into the tool chain has to be clarified in detail.
- A requirements management has not been set up for openETCS up to now. If ProR is chosen, it has to be interfaced with the shown Requirements Management Gateway with little effort.
- An "‘openETCS Eclipse Tool Chain Plugin"’ should be implemented (for convenience only).

A.8 Conclusion and other comments

The most challenging question is, how deep the openETCS functionality should be modeled semi-formal and when to start with formal modeling. The question could be answered best if focusing on adequacy: A justifiable balance of technical and non-technical aspects as feasibility, complexity, efficiency, overall effort, project schedule etc..

Using SysML/Papyrus with SCADE offers two different alternatives for semi-formal modeling:

1. Use SysML/Papyrus for semi-formal modeling by utilizing only the SysML language artifacts, for which an automatic transformation to SCADE exists today. The remaining – formal – modeling then has to be done with SCADE. Advantage: The interfacing between SysML/Papyrus is done, the tool chain already complete and ready for modeling right now. Disadvantage: The semi-formal SysML model will not be as comprehensive as the second alternative 2; there will be system aspects that only reside within the SCADE model, but not in the SysML model.
2. Use SysML/Papyrus for modeling all system aspects as far as justifiable with respect to understandability, maintainability, adequacy and effort. It requires the determination of a suitable subset of SysML to avoid the model becoming unrulable. Advantage: This approach leads to a most complete model on SysML level. It allows to benefit from future transformations between SysML and appropriate formal modeling languages, as soon as they may become available. Disadvantage: The openETCS project has to implement the transformation tools from SysML to formal modeling languages; for SCADE, that applies to all SysML artifacts not supported by the existing transformators.

In summary, alternative 1 is easy and ready to use and needs little effort. Alternative 2 offers more flexibility on SysML level but needs more effort and time. At least, finding a suitable balance between technical and non-technical aspects could answer the question.

The fact, that the SysML/Papyrus approach already exists and is operable, offers the chance to start the openETCS modeling process just now without delay. In parallel, a truly complete open source and open proof openETCS tool chain can be set up without causing unacceptable impact on the modeling work until it becomes mature enough for practical usage.

Appendix B: SysML, ERTMSFormalSpecs and Eclipse/Polarsys

The proposed approach combines three tools existing today to provide an integrated toolchain, from system design to code generation.

B.1 Description of the approach for OpenETCS design process

The proposed toolchain is illustrated in Figure B1.

The blue boxes of the overall design process are covered in the following manner:

SRS box: Using Papyrus for visualizing and editing the high-level ERTMSFormalSpecs model design in SysML language.

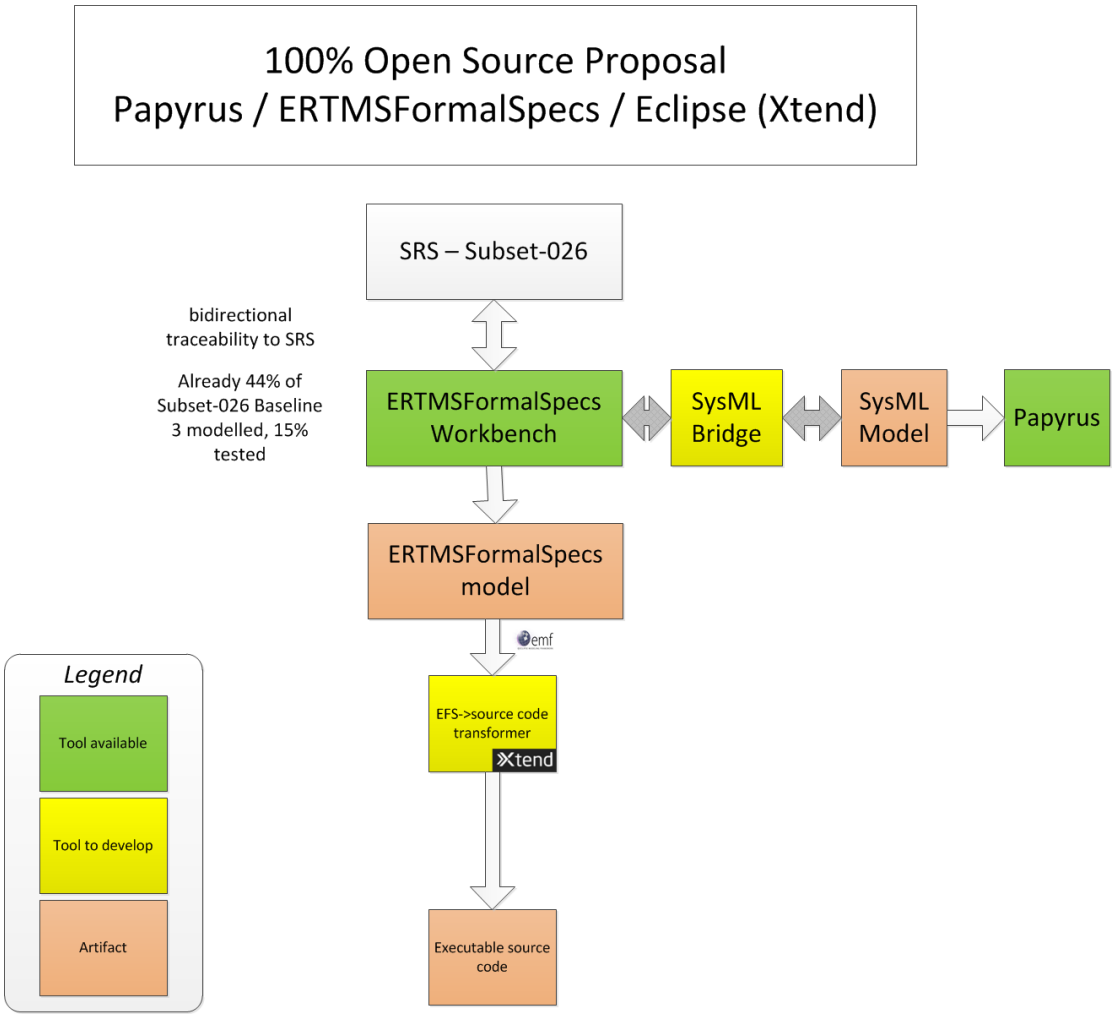


Figure B1. SysML, ErtmsFormalSpec and Eclipse/Polarsys Proposal

Sub-system semi-formal model box: Using ERTMSFormalSpecs to model the complete SRS into a semi-formal model.

Software semi-formal model + architecture description box: Shall be done inside the ERTMSFormalSpecs->source transformer box, using XText Eclipse framework. The ERTMSFormalSpecs->source transformer shall transform the ERTMSFormalSpecs model into target source code. The architecture and software model of generated source code is part of the ERTMSFormalSpecs->source transformer. The actual target language shall be chosen in agreement with WP5 (demonstrator).

Target source code box: This box is covered by the source code generated by the ERTMSFormalSpecs->source transformer. This source code can then be compiled and executed on the demonstrator hardware.

Note: The ERTMSFormalSpecs->source transformer is not available today, and shall have to be implemented in the scope of the OpenETCS project. This is detailed in further Shortcomings and Ongoing work sections.

Note: the ERTMSFormalSpecs->source transformer doesn't neet to be qualified according to CENELEC standards, to fullfill the two following objectives of the OpenETCS project, i.e. 1/ a complete Subset-026 semi-formal model and 2/ generated, non-vital source code running on demonstrator platform (See Section 3. OPENETCS PROJECT – SCOPE OF WORK AND OBJECTIVES in [6])

Note: How SysML is integrated with lower-level layers is an open discussion, applicable to all toolchains (SCADE, ERTMSFormalSpecs, B). Currently, none of them has proposed a complete, workable approach, enabling round-trip engineering between the higher-level design (in SysML) and lower-level (like SCADE model or ERTMSFormalSpecs model). In the meanwhile, without a clear and usable round-trip strategy is defined by the SysML experts (in collaboration with SCADE, ERTMSFormalSpecs, B experts for instance), the bidirectional arrows linking the ERTMSFormalSpecs model and the SysML model are put in grey, are they are subject to further study.

B.2 Integration of the approach with SysML/Papyrus

The proposed approach uses SysML/Papyrus as a visualization tool on the ERTMSFormalSpecs model. A SysML exporter component (yet to be developed) shall transform selected part of the ERTMSFormalSpecs model into SysML artifacts (state machines, interaction diagrams, module diagrams, data flows, etc) in order to improve readability of the ERTMSFormalSpecs model thanks to SysML.

In a second phase, if changes are brought to the SysML model, the SysML exporter component could be extended in order to provide round-trip engineering between the ERTMSFormalSpecs model and the generated SysML model, so that changes brought to the SysML model are propagated to the ERTMSFormalSpecs model.

Some questions are open:

- What is the optimal mapping between ERTMSFormalSpecs model elements and SysML diagrams and elements, in order to maximize model readability and verifiability? - How can round-trip engineering be implemented, to propagate changes brought to the SysML model back to the original ERTMSFormalSpecs model?

B.3 Integration of the approach with Eclipse

SysML/Papyrus is completely based on Eclipse.

ERTMSFormalSpecs supports today an EMF interface, enabling Eclipse-based tools to reuse the existing ERTMSFormalSpecs model.

Technically, ERTMSFormalSpecs is implemented mostly in C# and .Net (the ERTMSFormalSpecs workbench) and also has a java-based component, capable of exporting the ERTMSFormalSpecs xml model into an EMF store, so that the ERTMSFormalSpecs model can be accessed from the Eclipse world.

Eclipse/Polarsys tools are also based on Eclipse, raising no integration concerns.

B.4 Benefits versus OpenETCS requirements

The benefits of the SysML/Papyrus/ERTMSFormalSpecs/Eclipse proposal are the following:

- As of today, already 44% of Subset-026 requirements modelled. This proposal enables the OpenETCS project to start with a headstart, instead of nothing.
- ERTMSFormalSpecs is a semi-formal candidate to have built-in braking curves modellings and visualization, verified with the ERA model
- ERTMSFormalSpecs has very strong support for traceability to the Subset-026, and to the Subset-076 for test cases. More specifically, inside the ERTMSFormalSpecs workbench, every requirements of Subset-026 can be linked to one or more model artifacts. These links are used by the ERTMSFormalSpecs workbench to generate specification coverage reports. Tests from Subset-076 can also be linked to requirements of Subset-026. For more details, see the online ERTMSFormalSpecs User Guide. Note: traceability to/from SysML and to generated code remains to be addressed (see section ongoing work for OpenETCS project).
- ERTMSFormalSpecs has its domain-specific language, which is highly productive to model Subset-026, thanks to its expressivity, illustrated by the primitives developed for braking curves and scalable, as is demonstrated by the large fraction of the Subset-026 which has been modelled so far
- Fully open-source (ERTMSFormalSpecs under EUPL license, others open source).
- ERTMSFormalSpecs model can be transformed automatically to SCADE model (confirmed by ESTEREL Technologies in Munich meeting), allowing to choose SCADE as a code generation backend in case Eclipse/Polarsys would not meet the project requirements
- The three elements of the toolchain (Papyrus, ERTMSFormalSpecs and Eclipse) boast an active community of users and are supported by open-source business cases

B.5 Shortcommings versus OpenETCS requirements

The shortcomings of the SysML/Papyrus/ERTMSFormalSpecs/Eclipse proposal are the following:

- ERTMSFormalSpecs has a perfectible look and feel and lacks graphical rendering of the architecture. *This shortcoming might be addressed with the integration of SysML as a visualization language.*
- As of today, the code generation in Eclipse, transforming the ERTMSFormalSpecs in generated source code, is not yet available, and must be developed during task 3.8 of the project. This should be a relatively easy task, as the code generator doesn't need to be qualified according to CENELEC standards (See Section 3. OPENETCS PROJECT – SCOPE OF WORK AND OBJECTIVES in [6]).

B.6 On going work for openETCS project

The following elements should be further developed during the OpenETCS project, to alleviate the shortcomings listed above:

1. Develop conceptual and technical strategies to integrate SysML with ERTMSFormalSpecs model, going beyond the state-of-the-art. The state-of-the-art in integrating SysML models and industrial (semi-)formal languages being SCADE System, in which only the module, interfaces and dataflows are connected to the lower-level model.
2. Further develop ERTMSFormalSpecs model to cover 100% of Subset-026, 100% of Subset-076, and to fully test the model within ERTMSFormalSpecs.
3. Either implement a full eclipse-based version of the ERTMSFormalSpecs workbench for model development, traceability and testing, or improve the ERTMSFormalSpecs user interface to be fully productive for T3.5 and T3.6 tasks
4. Develop code-generation strategies during T3.8 tasks

Among theses tasks, Task 2 and 4 fit inside the WP3 existing tasks, and do not need additional skills than the ones present in the OpenETCS consortium as of today. Task 1 is also seriously represented in the consortium, in which a lot of SysML experience is present.

Task 3 (porting the ERTMSFormalSpecs workbench to Eclipse) is a task that falls in the scope of WP7, and for which Eclipse development and integration skills are required.

B.7 Conclusion and other comments

As a conclusion, the SysML/Papyrus/ERTMSFormalSpecs/Eclipse proposal has as 3 key strengths 1/ to be fully available today for the WP3 modelling tasks, which are the most urgent 2/ to already model 44% of Subset-026, and 3/ to be fully open-source.

Moreover, it proposes a realistic technical foundation to achieve the WP3 and projects top-priority objectives with the skills and resources available in the project.

Appendix C: SysML and Classical B

This section describes the approach of combining SysML modeling with Classical B. The technical realization is shown in Figure C1. Modeling starts in SysML based on the tool Papyrus. At the current stage of the project, it is undefined which SysML elements and diagrams will be used. This must be well defined to ensure that a transformation from SysML to Classical B is semantically correct. To validate the SysML model according to define modeling guidelines, the approach suggest the use of the *Object Constraint Language (OCL)* or the *Eclipse Validation Framework*. Such guidelines may restrict the usage of certain modeling elements and may enforce certain naming conventions.

The validated SysML model will be transformed to a Classical B model with a model-to-text transformation language (e.g. Xtend). The generated Classical B model is considered as read-only and is only allowed to be further refined. From that point, the existing Atelier B toolchain will be used for refining the model until reaching the implementation. Provers support the V&V

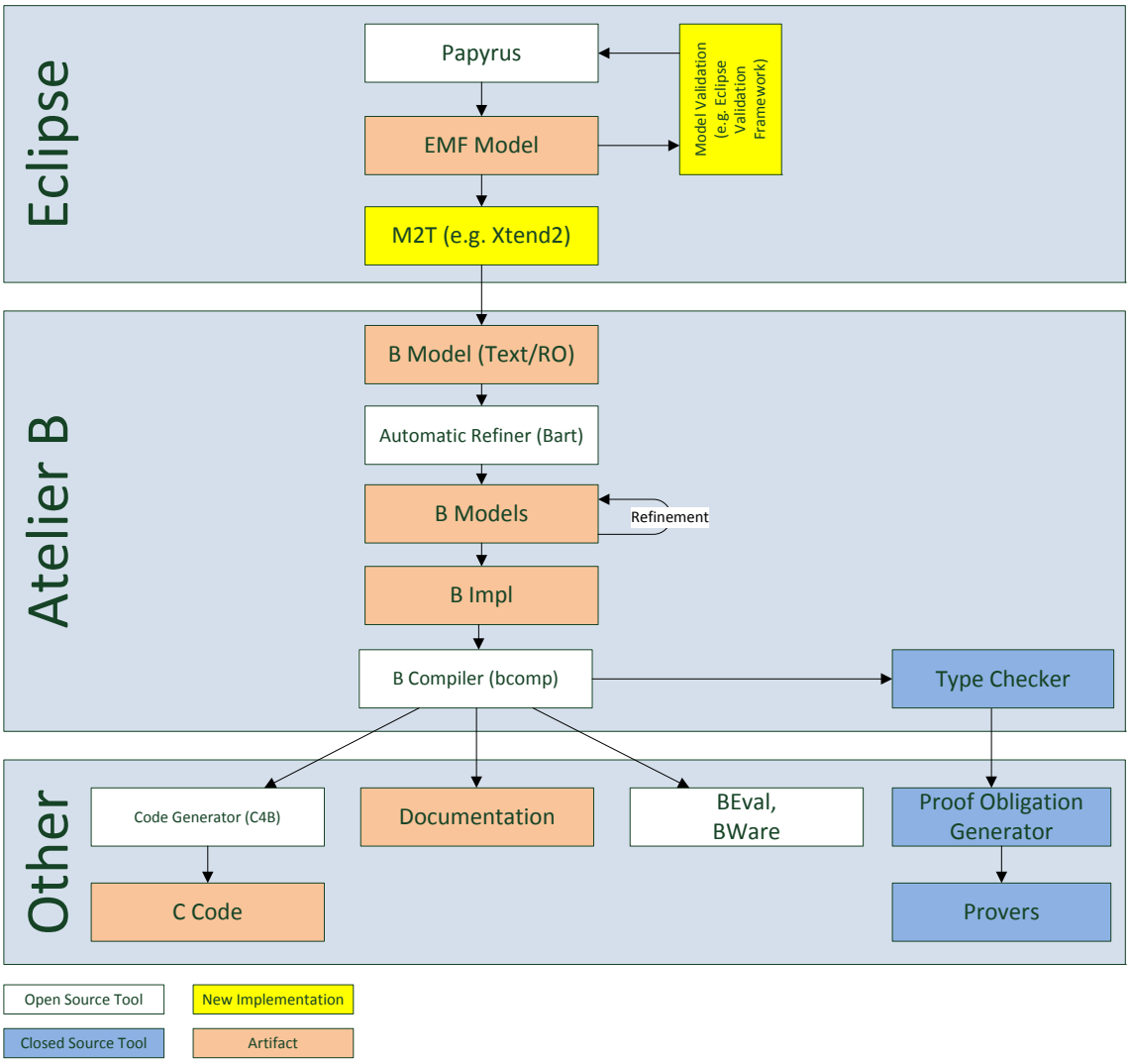


Figure C1. Technical overview of the Papyrus and Classical-B toolchain

Tool	License	Link
Bart (B Automatic Refinement Tool)	GPLv3	http://sf.net/projects/bartrefiner/
Atelier B GUI	GPLv3	http://sf.net/projects/atelierbgui/
Bcomp (B Compiler)	GPLv3	http://sf.net/projects/bcomp/
c4b (C Code Generator)	GPLv3	http://sf.net/projects/c4b/
ComenC (C Code Generator)	-	http://sf.net/projects/comenc/
BEval	EPL	http://github.com/ValerioMedeiros/BEval
BWare	-	http://bware.lri.fr/index.php/BWare_project
Papyrus	EPL	http://www.eclipse.org/papyrus/
Xtend	EPL	http://www.eclipse.org/xtend/
Type Checker	proprietary	-
B0 Checker	proprietary	-
Prover	proprietary	-
Proof Obligation Generator	proprietary	-

Table C1. Tools used in the Classical B toolchain

activities and the open source code generator c4b is capable of generating C code. However, the generated C code is not SIL4 certified. For SIL4 code generation, there is the option to replace it with a commercial T3 translator or to develop an own translator. As the software structure is closely captured in the resulting B model, the translation from B to the target language is less complex than it is the case with languages that lack this strong relationship.

The proposed toolchain is intended to be a first version. The yellow boxes in Figure C1 indicate non existing software artifacts that have to be developed within the openETCS project. Furthermore, it is desirable to move parts from the Atelier B tool into Eclipse.

In Table C1 the list of tools used in the proposed toolchain is given. The GPLv3 licensed tools are stand-alone executables. It is not expected that GPLv3 licensed tool will lead to license issues with EUPL code, as these tools are only executed and not linked with other parts of the toolchain. The ComenC code generator is listed in the table, because the current version of Atelier-B ships with it instead of c4b. The source code of ComenC is available, however it is unclear under which license the source code is distributed. The Type Checker, Checker, Prover and Proof Obligation Generator are currently only distributed under a proprietary license. However, with BEval and BWare (see Table C1) open-source alternatives are available. BEval is a tool which allows verification of models by model-checking with the ProB model-checker. In the BWare project a new open-source proof obligation generator is under development. Both tools could complete the toolchain to have open-source alternatives for V& V activities.

C.1 Description of the approach for OpenETCS design process

Taking into account the results presented in Section 2, the proposed toolchain completely covers both, the system phase as well as the software phase (see Fig. 3). SysML with Papyrus would be used for modeling the SSRS on analysis level. The same tools will be used for the sub-system semi formal model, which will be created during the sub-system formal design phase. The SysML models will then be transformed to Classical B models, with the intention to perform further development steps according to the B method.

For both, the sub-system strictly formal model and the software semi-formal model it is proposed to use Classical B. The development of the B model will be done by further refining the read-only B models, which was generated from the SysML model. It has to be investigated where *exactly* the transition between SysML and Classical B will be done. In particular, it is currently unclear which SysML language constructs and diagrams will be used that can be transformed to Classical B. The structure described in SysML with *Block Definition Diagrams (BDD)* and *Internal Block Diagram (IBD)* are obviously prime candidates for a transformation to Classical B, but which behavior diagram will can be transformed is still under investigation.

The last part of the development process is the code generation and it is proposed to be performed with an existing code generator tool (c4b).

C.2 Integration of the approach with SysML/Papyrus

On the technical side, the integration will be performed by utilizing the EMF framework of Eclipse. With an appropriate transformation language (e.g. Xtend), the SysML model can be transformed to a textual representation in Classical B. Whether or not it is advantageous to perform the transformation with an intermediate Classical B meta-model and an a mode-to-model transformation (see Fig. C2) is under investigation.

The semantic integration of SysML and B method imposes a greater challenge. There already exist literature regarding the alignment of SysML and the B method. The work in [1] provides such an alignment focusing on V&V, which could be used as a base for further research, that considers in particular the openETCS requirements.

C.3 Integration of the approach with Eclipse

The integration of the proposed toolchain is mainly done as described in the previous section. After using SysML, the used tool is changed to Atelier B. This obviously does not correspond to a fully Eclipse based toolchain. However, this proposal only reflects an initial toolchain, which could be improved during the project and beyond. The parts of the toolchain which are user visible and realized with Atelier B in the first version, could be progressively moved to an Eclipse based solution. The open source tools involved in the toolchain (automatic refiner, code generator, compiler, etc.) can be executed from the command line, which allows an easy integration into

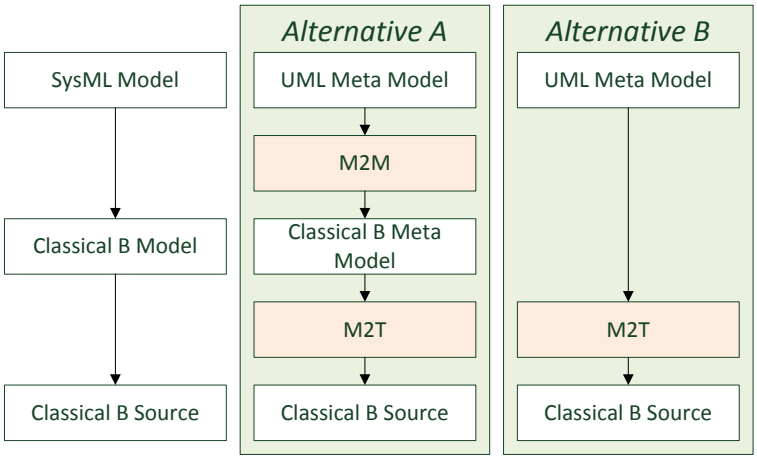


Figure C2. Alternatives in the transformation from SysML to Classical B

Eclipse. To what extend components from existing solutions (e.g. the Rodin platform) can be used and if there are enough resources available in the project, has to be investigated.

C.4 Benefits versus OpenETCS requirements

Both, SysML and the B Methods are accepted in the industry and have been successful used in the development of safety critical embedded systems. The B Method was used in projects like KVB by Alstom, SAET METEOR or in the driverless metro line 1 in Paris by Siemens Transportation Systems (see [3] for an extensive list).

Most parts of the toolchain are already available and distributed under an open source license. The transformation from SysML to B is the only missing software artifact, that has to be developed for the first version of the toolchain (see Fig. C1).

The project consortium includes partner with great expertise in both languages, SysML and B. By incorporating these expertise, there is a good chance that the proclaimed goals of openETCS will be achieved.

The modular architecture allows the exchange of certain tools with more powerful alternatives, even if they are closed-source. For example, there is a closed source code generator which allows the creation of ADA or C++ code. This code generator could be used as a drop-in replacement for the open-source c4b if necessary.

Furthermore, with Eclipse and Atelier-B versions for Windows, Mac OS and Linux, the most common operating systems are supported by the proposed toolchain.

C.5 Shortcomings versus OpenETCS requirements

Although the majority of the toolchain is open-source, there is still a small amount of tools which are closed source (see Fig. C1). During this project, these parts will be further investigated with the goal to be replaced by open-source equivalents.

A general weak point of the approach is the interface between Eclipse and Atelier-B. It would be favorable if the tool flow is only unidirectional. However, if during refinement steps in Classical B an bug in the initial B model is encountered, a correction in the original SysML model is necessary. This change triggers the generation of a new, initial B model. A bi-directional transformation could ease this issue, which would require a tighter integration of both tools. This is amongst other one reason why moving parts from Atelier-B to Eclipse should be further investigated. This issue applies to all proposed toolchains as all change at a certain point the modeling tool and the used language.

The example from the previous paragraph also show that the modeler should preferable have knowledge of both, SysML and Classical B. The reason is that otherwise bugs found in the SysML model during the Classical B development phase have to be fixed by the modeler of the original SysML model, which may be inefficient. This issue should be also considered when the border between SysML and Classical B is defined.

C.6 On going work for openETCS project

One of the most important parts is to define a subset of SysML which can be transformed to Classical B and preserves it semantics. Probably the other toolchains also need a restricted usage

of SysML, therefore a collaboration on this topic would be advantageous. Furthermore, it would be ideal if one subset could be defined, which is applicable to all proposed toolchains.

Another ongoing work is the precise definition of the border between SysML and Classical B. This work is also linked to the work described in the previous paragraph, as the border may have implication on diagrams used in SysML.

The transformation from SysML to Classical B must be planned and developed within this project. Furthermore, it must be investigated how traceability can be supported by this transformation, to allow bidirectional traceability from SysML artifacts to code. On the implementation part, a desirable skill is the knowledge of transformation languages in Eclipse.

Experience has shown that for model transformations the source model should be checked according to guidelines. An obvious one is naming as the source model may allow character combinations that are prohibited in the destination model.

To show the capabilities and to identify any currently unforeseen barriers, an early prototype should be developed which illustrates all steps using an example use-case.

C.7 Conclusion and other comments

The proposed toolchain based on SysML and Classical B covers the openETCS design phases from system analysis, sub-system formal design, software design and software code generation. Furthermore, an operational open source toolchain is already available from high level B model design to C code.

Both, the proposed languages and tools have industry acceptance and there exists a significant experiences in developing safety critical system with such languages.

With the exact definition of the border between SysML and Classical B, only the transformation between both languages has to be developed for an initial version of the toolchain. During the project, this initial version can be gradually improved to remove the last remaining closed-source (see Fig. C1) tools.

Appendix D: Errata

In the following, problems that were found after the release of this document are documented.

D.1 Top level in the V-model

Reported by Jan Welvaaarts at `https://github.com/openETCS/toolchain/issues/181`.

"At 8-10-13 decision 6 was accepted. In this requirement it is stated that sys-ML will be the top level in the V-model. However the top level specification in the V-model for openETCS shall be the written (prose) specification (SRS analysis and functional descriptions)."

Appendix: References

[1] Erwan Bousse, David Mentré, Benoit Combemale, Benoit Baudry, and Katsuragi Takaya. Aligning SysML with the B Method to Provide V&V for Systems Engineering. In *Model-Driven Engineering, Verification, and Validation 2012 (MoDeVVa 2012)*, Innsbruck, Autriche, September 2012.

[2] Cécile Braunstein and WP7 partners. Evaluation of tool platforms against the WP2 requirements. Results O7.1.9, OpenETCS, June 2013.

[3] ClearSy System Engineering. The B Formal Method: from research to teaching. Presentation held 16. June in Nantes, June 2008.

[4] Michael Jastram, Marielle Petit-Doche, Jonas Helming, and Jan Peleska. OpenETCS toolchain WP7 descritption of work. Definition D0W, OpenETCS, February 2013.

[5] Marielle Petit-Doche and Matthias Güdemann. OpenETCS process. Technical Report D2.3, OpenETCS, June 2013.

[6] Marielle Petit-Doche, Pierre-François Jauquet, Stéphane Callet, Merlin Pokham, and Stanislas Pinte. Wp 2, 3, 4, 7 : Safety workshop - meeting minutes, April 2013.

[7] Marielle Petit-Doche, David Mentré, and Matthias Güdemann. OpenETCS methods. Technical Report D2.4, OpenETCS, June 2013.

[8] Jan Welte and Hansjörg Manz. Report on existing methodologies. Technical Report D2.1, OpenETCS, June 2013.