Cross-domain Modelling of Verification and Validation Workflows in the Large Scale European Research Project VALU3S

Invited Paper

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Abstract. The complexity of systems continues to increase rapidly, especially due to the multi-level integration of subsystems from different domains into cyber-physical systems. This results in special challenges for the efficient verification and validation (V&V) of these systems with regard to their requirements and properties. In order to tackle the new challenges and improve the quality assurance processes, the V&V workflows have to be documented and analyzed. In this paper, a novel approach for the workflow modelling of V&V activities is presented. The generic approach is tailorable to different industrial domains and their specific constraints, V&V methods, and toolchains. The outcomes comprise a dedicated modelling notation (VVML) and tool-support using the modelling framework Enterprise Architect for the efficient documentation and implementation of workflows in the use cases. The solution enables the design of re-usable workflow assets such as V&V activities and artifacts that are exchanged between workflows. This work is part of the large scale European research project VALU3S that deals with the improvement and evaluation of V&V processes in different technical domains, focusing on safety, cybersecurity, and privacy properties.

Keywords: verification and validation, safety, cybersecurity, privacy, automated systems, V&V workflows, V&V tool chains

1 Introduction

In complex software-intensive systems, analytical quality assurance activities, especially verification and validation (V&V), on different levels have become crucial for achieving high product quality. The resulting systems have to fulfill a wide range of stakeholder requirements. Depending on the concrete properties to be assessed and the domain of the system being developed, different V&V methods and tools are applied. The underlying V&V process plays a key role for the efficiency of the quality assurance strategy and its implementation as a tool chain in the project. Workflows of the V&V activities have to consider multiple aspects of the development and quality assurance process. V&V workflows are closely linked to the requirements and constraints of the corresponding projects and use cases, as well as the V&V framework, methods and tools that are used.

The remainder of the paper is structured as follows: The VALU3S project with its objectives is introduced in section 2. Section 3 summarizes goals and first results of the different work packages in the project. The workflow modelling approaches with its notation and tool-support is introduced in section 4. Finally, section 5 summarizes the main conclusions.

2 The VALU3S Project

The ECSEL JU (Joint Undertaking) project VALU3S focuses on the V&V of cyber-physical automated systems with respect to safety, cybersecurity and privacy (SCP) requirements. The project aims at the design and implementation of V&V methods, tools and tool chains that reduce the time and effort needed to assure the SCP requirements [1][2]. The main assets of the project and the correlating work package (WP) numbers are illustrated in Fig. 1.

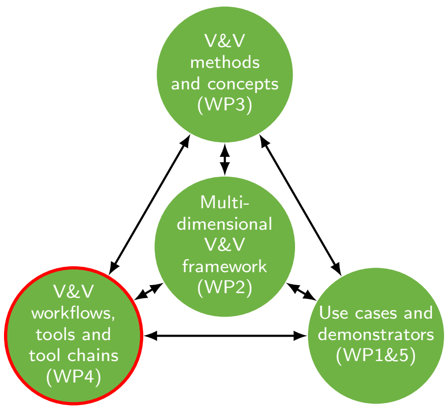

Fig. 1. VALU3S Project Assets

This paper reports on the current status of the activities connected to creation and detailing of V&V workflows. VALU3S also aims to create and evaluate a multi-domain verification and validation framework, which facilitates the evaluation of automated systems from component level to system level. This way, the project provides practitioners with detailed information about all components involved in the V&V process. Such information is then used to facilitate the V&V process through the identification of V&V tools, concepts and processes used in different application domains targeted by the project. These domains are *automotive*, *agriculture*, *railway*, *healthcare*, *aerospace*, and *industrial robotics*.

In order to ensure and show the broad applicability of the results (framework, improved methods and tools, etc.), demonstrators will be built from the 13 use cases selected in the project from the target domains.

2.1 Project Objectives

The high-level objective of the project is to design, implement and evaluate state-of-the-art V&V methods and tools that reduce the time and cost needed to verify and validate automated systems with respect to SCP requirements. In order to achieve this objective, the following sub-objectives are defined and are planned to be followed-up on during the execution of the project:

- *Objective 1.* To develop a Multi-layered framework enabling more effective verification and validation
- *Objective 2.* To overcome the SCP gaps and limitations of cyber-physical systems
- *Objective 3.* To present a novel, standards compliant V&V workflow that is generic to reference methods in selected cyber-physical domains
- *Objective 4.* To demonstrate, verify and validate the usefulness and wider acceptance of the proposed framework by realistic pilots
- *Objective 5.* To suggest and validate new as well as state-of-the-art evaluation scenarios for safety, cybersecurity and privacy evaluation
- *Objective 6.* To develop and improve V&V tools and evaluation criteria
- *Objective 7.* To revisit and identify the weaknesses of relevant safety and security standards and develop a concrete strategy to influence the development of new standards
- *Objective 8.* To present guidelines for end users and practitioners as well as to disseminate the project results aiming to increase the awareness on the importance of conducting SCP V&V.

Note that multiple KPIs (key performance indicators) have also been defined to facilitate the monitoring of obtaining the project objectives. Nine of the KPIs defined are used to monitor the project's progress from the technical point of view, while multiple other KPIs are defined to monitor the project's impact through conducting dissemination (8 KPIs), exploitation (7 KPIs), standardisation (1 KPI), and communication (8 KPIs) activities.

3 Project Structure and Work Packages

VALU3S is structured into six technical work packages and one management work package. The following sub-sections describe goals and first results from technical work packages, covering the industrial use cases, the multi-dimensional framework, the V&V method library, the systematic evaluation, and the dissemination and exploitation activities.

3.1 Industrial Use Cases in VALU3S

In WP1, 13 use cases were described in detail, covering all six domains of *automotive*, *agriculture*, *railway*, *healthcare*, *aerospace*, and *industrial robotics*. Some domains include a single use case (e.g., *Aircraft engine controller* in the domain of *aerospace*), while others have multiple (e.g., *Intelligent Traffic Surveillance*, *Car Teleoperation*, *Radar system for ADAS* in the *automotive* domain).

For each use case, several evaluation scenarios, SCP requirements, and test cases were defined and collected in repositories: The evaluation scenarios encompass a high-level classification of the underlying test requirements and a description of what needs to be evaluated and why. The SCP test requirements define a required behavior of a system in a corresponding scenario and will be the basis the systems and demonstrators will later be verified and validated against. The test cases are derived from the evaluation scenarios and test requirements and describe how a test of a certain scenario should be conducted, with regard to safety, cybersecurity and privacy requirements.

The test cases were then mapped on the multi-dimensional framework that was developed in WP2. The test case descriptions were expanded to include references to other framework elements, namely the V&V methods to be used (previously defined in WP3), the components that are tested, and relevant evaluation criteria (as defined in WP5).

In total 57 evaluation scenarios, 239 requirements, and 192 test cases were defined in WP1. To find similarities and possibly synergies between scenarios, requirements, and test cases, a commonality evaluation was conducted, identifying common points across all use cases. This plays an important part in the establishment of a real multi-domain V&V framework and will be taken advantage of during the demonstrator implementation.

3.2 Multi-dimensional V&V Framework

The main objective of WP2 is to create a multi-dimensional layered framework for V&V of automated systems with respect to SCP requirements. The framework will be represented as a web-based repository where all elements of the framework will be stored. Taking as input the VALU3S framework, the Web repository is intended to serve as a searchable catalogue of V&V methods applicable to specific domains and application scenarios. The repository is planned to be updated throughout the course of the project to take into account all the outputs of the project. To this end, the first step is to design a multi-dimensional framework defining a clear structure around the components and elements needed to conduct V&V processes through identification and classification of evaluation methods, tools, environments and concepts that are required to verify and validate automated systems with respect to SCP requirements. The second step is to develop a web repository based in the multi-dimensional framework to store the V&V information created by each of the Use Cases and tasks of VALU3S project. The last step of WP2 is to populate the web repository with the information regarding V&V activities carried out in the project. The Web repository will be populated with the test cases and requirements specification detailed in WP1, V&V methods in WP3, V&V tools identified and developed in WP4 and the evaluation results of the V&V process in WP5. The repository will store also main WP outputs such as V&V methods, processes and tools.

The framework specifies which data related with each V&V activity must be collected and defines the data format. Through a structured classification of the components required for the V&V of automated systems, the framework provides practitioners with detailed information about all components involved in the V&V process. That information facilitates the V&V process through identification of state-of-the-art V&V methods, tools and processes used in different domains, as well as the application of those methods to use cases. The framework is therefore a key instrument to achieve the main objective of the project, which is the design and development of V&V methods and tools that shorten time and lower cost of V&V processes. In order to describe the design and structure of the V&V multi-dimensional framework, a meta-model as a UML class diagram has been created with the V&V methods as its central elements. These methods are categorized using the dimensions, by means of many-to-one and many-to-many relationships between the V&V method entity and the various dimensions. The framework currently has 8 dimensions and is also layered as the evaluation process may include multiple alternatives to choose from in each of the dimensions, see Fig. 2.

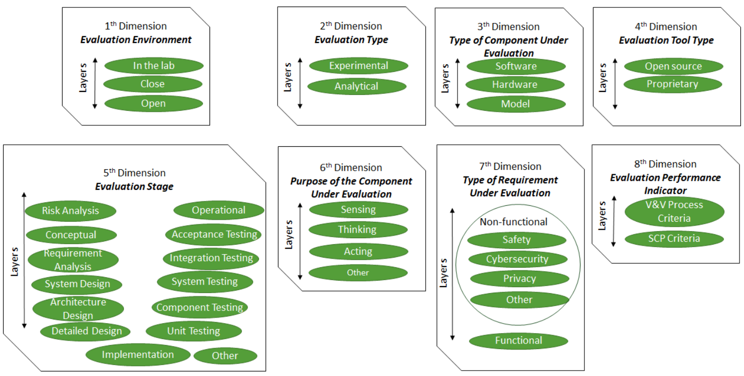

Fig. 2. VALU3S multi-dimensional layered framework

3.3 V&V Method Library

In the project WP3 focuses on developing new methods, method improvements, and innovative combinations of methods for V&V. In a first step, fifty-three V&V methods have been identified, described and characterised [3]. The methods fall into the following (not strictly disjoint) categories:

1. *Injection*: introducing some phenomenon in a system to analyse its response.
2. *Simulation*: studying the behaviour of a model of a system.
3. *Testing*: checking system execution under certain conditions before operation
4. *Runtime verification*: evaluating system execution during operation.
5. *Formal analysis*: for V&V methods with a mathematical basis.
6. *Semi-formal analysis*: for V&V methods that exploit some structured means but without a full mathematical basis.
7. *Informal analysis*: for V&V methods that do not follow any predefined structure or have mathematical basis.

They were analysed for improvement potential from two directions: a) known limitations and weaknesses of the methods and b) needs of the use cases that are currently not sufficiently addressed by the methods. This analysis led to a set of 400 gaps that could be addressed. The gaps fall into one of nine types: Functionality, Accuracy, Scalability, Deployment, Learning Curve, Reference Environment, Costs, Lack of Automation, and Standards. Figure 3 shows the distribution of gaps over these gap types and over the method categories.

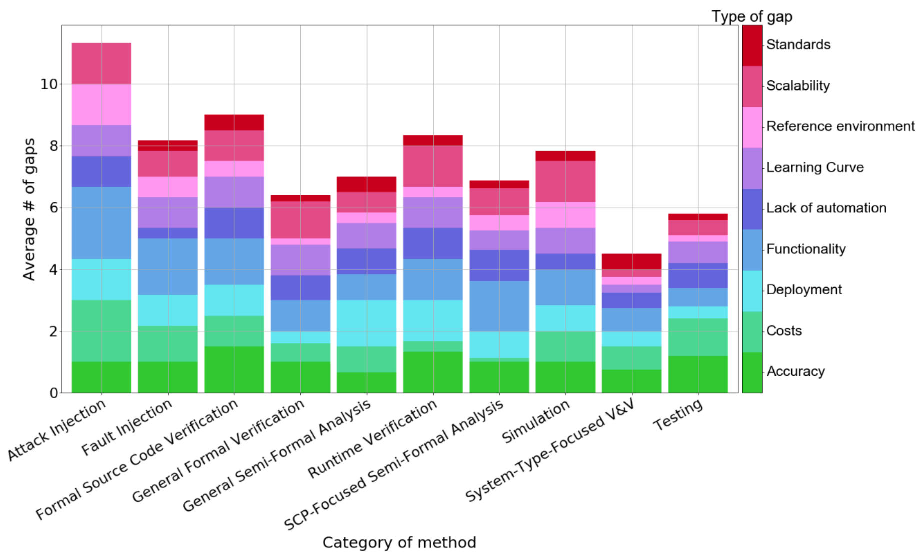

Fig. 3. Identified gap types distributed over method categories

Realistically, only a sub-set of gaps will be successfully solved, but a first collection of planned method improvements and new method combinations already led to sketches for 37 method improvements and 4 new method combinations, addressing 145 of the gaps. The methods and their implementations into tools form the building blocks for the V&V work-flows blocks. But there are also method-internal flows that need to be documented and communicated.

3.4 Demonstration and Evaluation

The VALU3S project is use case driven which means that improvement in engineering processes, especially their V&V parts, is motivated by real problems from industry and will be demonstrated on real development and verification and validation. Some of the designed V&V workflows or their parts will be shared by several use cases targeting some commonalities among them. The commonalities are either in the same domain, namely but not limited to detecting objects using radar in traffic surveillance and in an ADAS system, or across domains like remote control of a car (automotive domain) or a robot (agriculture domain). These workflows can share the same V&V approach using the same toolchain. On the other hand, there is also diversity in engineering processes which comes from different product-specific requirements, the size of engineering team, and/or the team's level of expertise of V&V methods. Improvement of V&V can be achieved by different ways following different V&V workflows.

Improvement of V&V can directly target the quality of developed product and/or the quality of used process to create the product. These two approaches are closely related. By utilising a new verification method which will require more effort in the V&V process, one can uncover previously unknown bugs leading to better quality of a product; on the other hand, by applying automated tools, the effort in V&V can be lowered while gaining the same results. The design and development of V&V workflows and tool chains will be adjusted to the needs of use cases focusing on improving the quality of their V&V.

Since quality of a product and a process are related and product- and team-specific, there is a need for objective criteria for collecting feedback from the evaluation of the improvements. In WP5, several criteria are provided aiming at different aspects of quality of a product and overall effort spent in V&V. Some of these criteria are already used in practice for years, but most of them focus on some specific aspects and are unable to provide objective measurements. The evaluation of improvement should combine all the parameters of quality. There are two lists of criteria proposed for the evaluation. One set of criteria are used for measurement of the quality of a product focusing on safety, cybersecurity, and privacy attributes. The other criteria focus on the measurement of improvement of the V&V process.

The set of criteria targeting SCP attributes include 17 different evaluation criteria, each of which uses different metrics or items to measure. The most commonly used criterion is the number or ratio of fulfilled product requirements in VALU3S, the criterion is used or planned to be used by 9 out of 13 use cases.

There are also 7 completely new criteria previously not documented or defined before.

The set of criteria used for measurement of a V&V process includes 13 evaluation criteria. The most commonly used criterion in practice focuses on the workforce needed for the engineering phases (overall 7 use cases in VALU3S). There are 4 new criteria focusing on time, cost, and effort spent on V&V processes directly or indirectly (see Table 1).

Table 1. Overview of new evaluation criteria

Evaluation criteria for SCP	Evaluation criteria for V&V process
Likelihood of faults and attacks Potential impact of incidents and attacks Reliability measures of decisions Number of attack/incident typologies examined Accuracy of simulated sensor output Simulator environment quality Simulator environment functionality	Time of test execution Joint management of SCP requirements Reduced cost and time for work on certification process and functional safety Workforce required to the user for preparation and running the tool

3.5 Dissemination, Exploitation, and Standardization

WP6 of the project is concerned with ensuring that the work and results of VALU3S are properly conveyed to the target stakeholders and audiences, which include industry and academia members who work on the V&V of automated systems, and standardization bodies that can benefit from the project's outcomes. For that, the several tasks of the work package have planned and defined the necessary activities focused on dissemination, training, exploitation, standardization, and communication that will guarantee the aimed impact of VALU3S' results. The implementation of the plans has already made considerable progresses and the first outcomes are described below.

In terms of *dissemination and training*, the main activities were concerned with the implementation of the internal communication channels, the definition of publication rules, processes, KPIs, and the monitoring of dissemination actions. In terms of training, two training sessions consisting of 11 presentations covering various V&V methods identified and classified under the activities of work package 3 have been organized (the videos of the presentations were made publicly available in the project's YouTube channel [16]).

In what concerns *exploitation*, most of the effort has been directed towards the collection of the necessary information that facilitates identification of exploitable results, the means of exploiting these results, the target stakeholders, and establish the plans to implement the exploitation strategy. To measure the effectiveness of the actions performed within the project, KPIs have been defined for that purpose.

In the context of *standardization*, the focus was given to standards and standardization initiatives related to the work in VALU3S. For that purpose, a survey was designed based on a list of initially identified standards with the objective of collecting further relevant standards and start the evaluation of relevant methods, tools and approaches related to the work planned for the project. After a detailed analysis, a set of initial standards have been defined as the primary focus of the project.

Finally, for *communication* purposes, the focus was given to relevant actions like implementing blog articles with high-level technical content, production of communication materials and, importantly, setting up and triggering the actions for the creation of liaisons with other related R&D projects in order to maximize the impact of dissemination and communication activities. Communication in the project's social media channels has also been a key activity that includes regular posts of partners profiles, announcement of new project publications, and also videos related to activities in the project.

4 Modelling of Verification and Validation Workflows

The efficient conduction of software development and quality assurance activities in complex projects require their systematic description and modelling including their sub-activities, execution steps, and work products that they process and produce and the provision of appropriate tool support for executing the activities. In WP4, a generic V&V workflow design approach and modelling language has been developed to allow tool-supported and highly automated instantiation to specific industrial use cases and implementation as concrete tool chains. The solution have paved the way towards the efficient evaluation and optimization of V&V workflows and tool chains for specific quality properties. The activity has been performed in close cooperation with the V&V method library to support the systematic description, extension, and gap analysis of V&V methods. The following sub-sections give a general introduction into workflows, the project requirements for V&V workflows, and the VALU3S solution assets with the VVML modelling notations and the tool-support for workflow modelling.

4.1 Introduction into Workflow Modelling

A process workflow is an orchestrated and repeatable pattern of activities, enabled by the systematic organization of resources into processes that provide services or process information. It consists of sequences of operations and supports a user task [13]. Process workflows refer to a series of activities or tasks that need to be completed sequentially or in parallel to achieve a business outcome. Process management is about how to create, edit and analyse predictable processes that improve the core of a business.

Basically, a workflow is a sequence of tasks that processes a set of data. Any time data is exchanged between systems and humans, a workflow can be defined. In general, the process is non-variant and proceeds in a sequence determined by actions or pre-defined business rules. In a standard workflow, with the automation of procedures where documents, information or tasks are passed between participants according to a defined set of rules, an overall business goal is aimed to be achieved. In the VALU3S project, a V&V workflow is understood as a reusable V&V activity pattern.

4.2 Workflow Modelling Notations

The application of process workflows for software and systems engineering activities with dedicated models and notations started in the late 1990s with the introduction BPMN [5] and adaptations of behavior models in standardized modelling languages like UML activity diagrams [6].

BPMN is a graphical illustration of business processes which aims to provide easy and understandable notations for different user groups including business analysts, technical developers, and business managers. It has become part of the OMG standards [5]. BPMN defines workflows with specific patterns and so-called Business Process Diagrams.

UML is a general purpose-modelling language, which is popularly used in software engineering for specifying, visualizing, constructing, and documenting artifacts in software applications [6]. UML provide various notations for representing behavior including Activity Diagrams, which enables the description of sequential and parallel flows of activities.

In given notation formats, BPMN and UML are commonly used in process modelling. There are some differences between BPMN and UML in diagramming the sequence pattern. Both notations use rounded rectangles in activities and utilize directed lines to show the direction of flow [14]. However, UML is a general-purpose visual modelling language that is more than a visual notation tool. BPMN is a modelling notation which aims to be easily understood by all business users [15].

In given modelling languages, it is possible to represent the same workflow in many ways. While flexibility of the modelling notations offer variety of solutions, not each individual is expert in these modelling languages or notations. For the workflow modelling notation, specific requirements and constraints from V&V process stakeholders have been collected in the project:

- simple and clear notation, i.e., providing few element types and few diagrams
- based on behavior modelling approaches in software engineering
- implementable in state of the practice modelling frameworks
- exchange of artifacts between V&V methods
- decomposition of V&V methods as implementation of sequences of lower level activities, which enable the stepwise production of output artifacts
- composition of methods to higher level methods
- preparation for automated and tool-supported analysis of V&V workflows

The generic workflow modelling notations from the previous subsection do not completely fulfill the requirements listed above. Therefore, a novel modelling notation based on a domain-specific language that represents the V&V perspective has been developed.

4.3 Tool-Support for Workflow Modelling with Enterprise Architect

In order to facilitate the application of the modelling approach, tool-support has been provided using the Enterprise Architect (EA), a UML modelling tool by Sparx Systems [4]. In EA, new modelling languages can be created with UML-Profiles, which can be used directly afterwards or can be packaged into an MDG (Model Driven Generation) Technology for more comfortable use. MDG Technologies seamlessly plug into Enterprise Architect to provide additional toolboxes, diagrams, UML profiles, shape scripts, patterns, tagged values and other modelling resources. Such an MDG technology, automatically generates a list of elements and relationships in the Diagram Toolbox, for each of the diagram within the technology, therefore implementing the V&V framework using the MDG Technology rapidly decreases the effort and simplifies the modelling of V&V workflows for VALU3S. EA provides a simple user-friendly interface for modelling of V&V workflows by specially customized diagram types enabling modelling workflow with V&V methods, V&V work products, sequential control flows, quasi parallel control flows, and flow of work products.

4.4 The VVML Modelling Language

In modelling languages such as UML, it is possible to represent the same idea in many ways. While the flexibility that the language has offers its positive aspects, it also brings problems in communicating ideas effectively. By creating a dedicated domain specific language (DSL) that clearly specifies what diagrams and elements can be used in creating a V&V method definition or its workflow, everyone follows a common standardized notation. Modelling V&V workflows falls into a specialized domain that requires a tailored modelling approach for activity models. To meet such requirements, there is a need to develop a UML profile for V&V Modelling Language – shortly VVML profile – introducing a set of model constructs and deploy the UML profile with other extension mechanisms as a modelling framework enabling rapid modelling of V&V workflows. Two levels of modelling are considered:

1. V&V Method Specification
2. V&V Workflow Definition

V&V Method Definition The V&V method definition enables the design of the base elements of the workflow. It provides an overview of the main V&V method properties such as name, interfaces, artifacts, and constraints. Three element types *Method*, *Artifact*, and *MethodArtifact* are defined (see Figure 4).

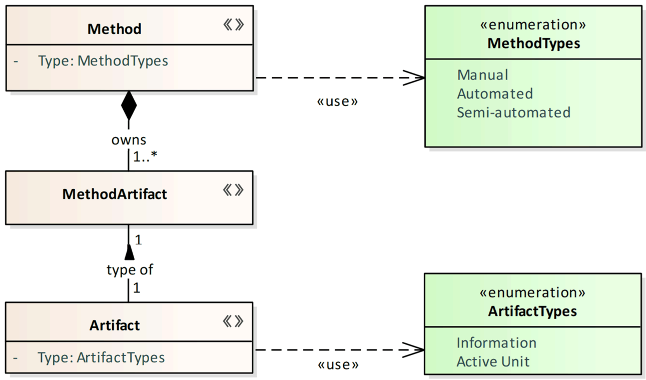

Fig. 4. VVML Modelling Elements

The modelling element *Method* is a unit that represents a process workflow dedicated to a specific V&V phase. It has a defined method type, which is currently used to represent the automation level, here: automated, semi-automated, or manual. The type *Artifact* is an object that is exchanged between methods or activities within methods. It has a dedicated type. An *Artifact* is either an information object or an active unit, i.e., program code or executable. Every *Method* owns a set of *MethodArtifacts*, which represent the method interfaces for the *Artifacts* that they consume or produce. A *Method* shall produce at least one output *Artifact* to show the external use of the *Method*. The meta-model for three main element types of VVML is shown in Figure 4.

An example for a V&V method definition with its artifacts and interfaces using the EA profile is given in Figure 5.

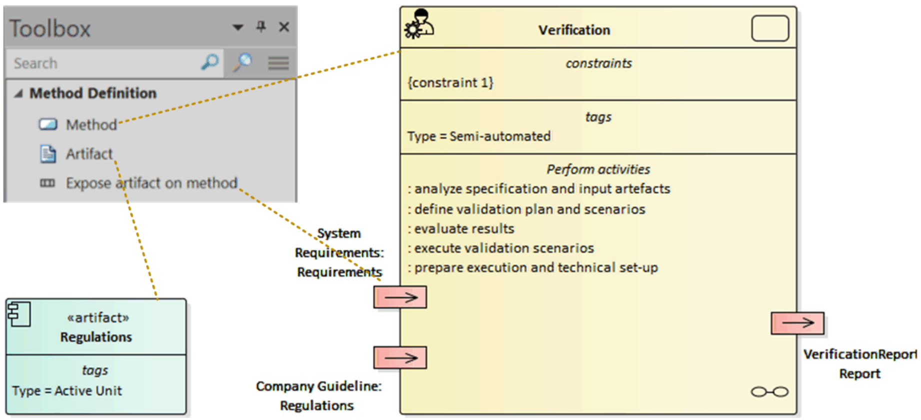

Fig. 5. VVML Modelling Elements

The EA profile provides a dedicated toolbox for designing new elements, i.e., methods, artifacts, and method interfaces. The method is represented by a yellow box with its name, constraints, tags, and sub-activities. Additionally, the method artifacts as input and output interfaces are annotated as red rectangles with arrows. Interfaces with arrows pointing to the method correspond to inputs such as *Requirements* and *Regulations* in the example. Interfaces with arrows pointing to the environment represent output artifacts like the *Verification Report*. The example also contains the definition of an artifact *Regulations*, which is referenced by the method in its interfaces.

V&V Workflow Definition The actual implementation of a V&V Workflow is specified by the V&V workflow definition. Its main purpose is to organize and specify the composition of activities, to reflect their sequential dependencies and the internal flow of artifact while executing the method. Table 2 presents elements of the V&V workflow implementation.

Table 2. VVML Workflow Definition Elements

Element	Decription
Start Workflow	Node that initiates the beginning of a workflow
Stop Workflow	Node that indicates the end of a workflow
Activity	Atomic action that is not further decomposed into steps
CallBehavior	Invocation of another method, which is further decomposed in another method workflow diagram
Activity Artifact	Activity interface for its input and output artifacts
Gateway	Branching of sequence flow based on condition
Fork / Join	Enables parallel sub-paths of sequence and artifact flows
Sequence Flow	Sequential connection of VVML activities
Artifact Flow	Exchange of artifacts between activities or from/to method interfaces

The workflow definition is also supported by the profile with a dedicated diagram type and toolbox. An example of a workflow definition in EA is shown in Figure 6. A workflow defines *Control Flows* and *Artifact Flows*. A *Control Flow* is defined by sequences of *Activities* that are executed in a defined order. Branches in the *Control Flow* are supported by *Gateways*. Quasi parallel execution is realized by *Fork* and *Join* Elements. *Start* and *End Nodes* indicate beginning and ending of a workflow. Activities can exchange *Artifacts* through their interfaces, which define the *Artifact Flow* of the workflow. The internal artifact flow is defined between activities, whereas the external artifact flow is defined from the method interfaces to the activities for method inputs or from the activities to the method interfaces for method outputs. In the example, two method inputs (*Requirements* and *Regulations)* are internally processed and one method output (*VerificationReport*) is provided to the environment.

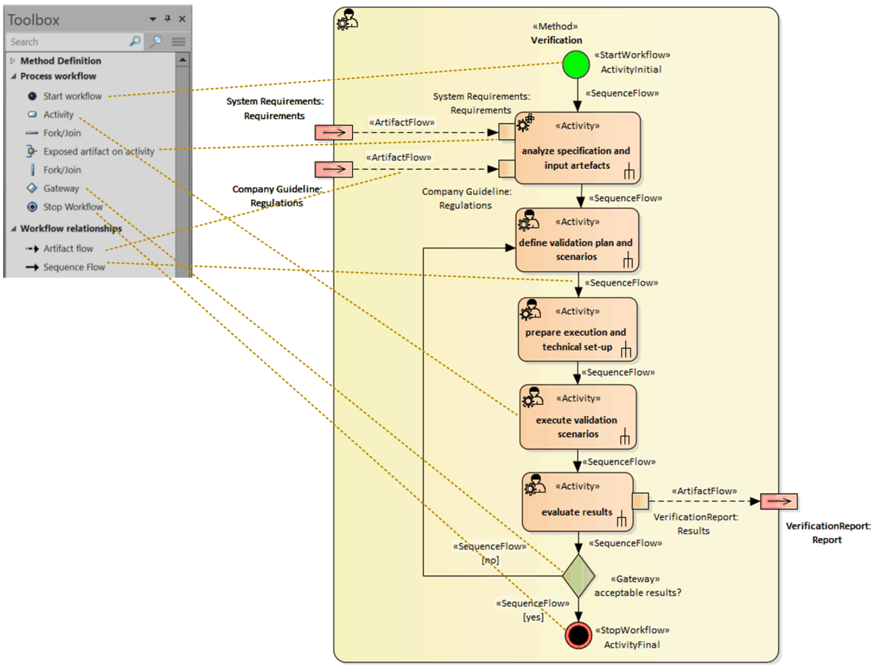

Fig. 6. VVML Sample Workflow

5 Conclusion

In this paper, the VALU3S ECSEL JU project is presented with its structure and first outcomes of the different work packages, covering the industrial use cases, the multi-domain V&V framework, the V&V methods, workflows and tool chains, the evaluation and demonstration approach, and the dissemination and exploitation activities. The modelling approach of the verification and validation activities is described in detail with its modelling notation VVML and the tool-support using the Enterprise Architect framework. The two levels of VVML are presented. The first one covers the base elements: methods, artifacts, and method interfaces. The second level enables the definition of workflows with sequences of activities and internal artifacts flows.

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