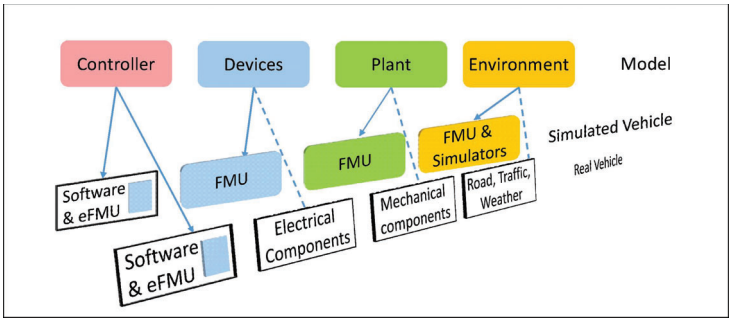
EMISYS

EMbedded systems Integrated SYStem development with physical models in large-scale simulation and production software

Integrerad utveckling av inbyggda system med fysikaliska modeller i storskalig simulerings- och produktionsprogramvara

Publik rapport



Författare: EMISYS Consortium
Datum: 2022-08-30
Projekt inom FFI Elektronik, mjukvara och kommunikation

Innehållsförteckning

Kort om FFI

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1 Sammanfattning

Inbyggd programvara utgör grunden för autonoma, elektrifierade och uppkopplade fordon, men det finns flera utmaningar relaterat till denna teknologi. Målet med detta projekt var att bidra till förbättrade utvecklingsmetoder för fordonsinbäddad programvara och att möjliggöra ny teknik för fordonsburen mjukvara för styrning och reglering.

Projektet har undersökt flera aspekter relaterade till utveckling av mjukvara och dess integration med komponenter som representerar mekanik och mekatronik:

- För- och nackdelar med uppdelningen i flera FMU för samsimulering
- Hantering av variabilitet och noggrannhet
- Kodgenerering och integration med FMI och eFMI
- Användningsfall och testning

Ett prototypramverk baserat på EAST-ADL och Modelica open source-verktyg har utvecklats under projektet. Prototypramverket integrerar verktyget ArEATOP för AUTOSAR- och EAST-ADL-modellering med OpenModelica-verktyget för Modelica- och FMI/SSP-modellering. Prototypramverket har testats på flera exempelsystem.

Projektmålen och deras status ges nedan:

Mål	***Resultat***
Ett modellerings-, konfigurations- och simuleringsramverk för integration av FMU/eFMU samt effektiv simulering av integrerade storskaliga fordonsundersystem.	*Projektet har utvecklat ett prototypramverk baserat på EAST-ADL och Modelica open source-verktyg.*
Förbättring av Volvo Trucks Eclipse-baserade programvara, baserad på AUTOSAR- och EAST-ADL-arkitekturmodelleringsrepresentationen, integrerad med ovannämnda ramverk.	*Utveckling och justeringar har gjorts, men på grund av resursbegränsningar, endast i liten skala.*
Utvärdering av den nya öppna standarden eFMI, (FMI for Embedded Systems, utvecklad i EMPHYSIS-projektet) i relation till Volvo Lastvagnars behov.	*Standarden har teoretiskt undersökts och bedömts, men praktiska experiment harinte varit möjliga. Detta berodde både på brist på resurser och på att verktyg och teknik saknades för eFMI-experiment. Återkoppling på eFMI-teknologin har lämnats till eFMI-konsortiet och EMPHYSIS-projektet.*
Förbättring och utvärdering för Volvo Lastvagnars behov av kodgenereringstekniker som främst utvecklats i EMPHYSIS-projektet.	*Detta mål uppnåddes inte på grund av att det saknades verktyg med öppen källkod för eFMI-generering.*
Framtagande av demonstrator som representerar ett komplett fordon med flera ecu, bussar, fordonets fysiska komponenter, modellerade som FMI/eFMI-komponenter tillsammans med vanliga AUTOSAR-programvarukomponenter.	*Istället för det avsedda större exemplet användes flera, enklare demonstratorexempel. Detta berodde på brist på resurser men också begränsningar av modellerings- och simuleringsteknik.*

2 Executive summary in English

Embedded software is an enabler for autonomous, electrified and connected vehicles, but several impediments are limiting its full potential. The goal of this project was to enhance the development process for automotive embedded software and to enable novel technologies for vehicle monitoring and control.

The project has investigated several aspects in the development and integration of software components with cyber-physical components:

- Pros and cons on the splitting of the cyber-physical system into several FMUs for co-simulation
- Handling of variability and fidelity
- Code generation and integration with FMI and eFMI
- Use cases and testing

A mature prototype framework based on EAST-ADL and Modelica open source tooling has been developed during the project. The prototype framework integrates the ArEATOP tool for AUTOSAR and EAST-ADL modeling with the OpenModelica tool for Modelica and FMI/SSP modeling. The developed prototype framework has been tested on several use cases.

The project goals and their status is given below:

Goal	***Result***
A modeling, configuration and simulation framework (M&C&S) supporting composition of FMUs/eFMUs and efficient simulation of integrated large-scale vehicle subsystems.	*The project has developed a mature prototype framework based on EAST-ADL and Modelica open source tooling.*
Enhancement of the Volvo Trucks Eclipse-based software, based on the AUTOSAR and EAST-ADL architecture modeling representation, integrated with the abovementioned M&C&S framework.	*Evolution and adjustments have been made, but due to resource constraints, only on a small scale.*
Evaluation for Volvo Trucks needs of the new eFMI open standard, (FMI for Embedded Systems, developed in the EMPHYSIS project).	*The standard has been theoretically investigated and assessed, but the practical experiments were not made. This was both due to lack of resources and because of missing tooling and technology for eFMI experiments. Feedback on the eFMI approach has been provided to the eFMI consortium and EMPHYSIS project.*
Enhancement and evaluation for Volvo Trucks needs of the new code generation techniques primarily developed in the EMPHYSIS project.	*This goal was not addressed due to missing open-source tools for eFMI generation.*
Whole vehicle subsystem demonstrator, with multiple ECUs, buses, vehicle physical components, modeled as connected FMI/eFMI components together with regular AUTOSAR software components.	*Instead of the intended larger example, multiple, simpler demonstrator examples were used. This was due to lack of resources but also limitations of modeling and simulation technology.*

3 Bakgrund

There is growing demand for automobiles and trucks to be safe, clean and efficient. For example, automation and electrification increase performance and capability requirements on the in-vehicle systems and related complexity, variability and shorter cycles put demand on development processes. OEMs as well as Tier1 suppliers try to cope with these demands by using physical models as part of the control software.

The increasing complexity and number of functions in future vehicles lead to high growth trends (from 6.3% to 10.8% depending on the functions), with a potential 2020 market of 46bn$. As ECU design mainly impacts non-recurring costs, the market size is a limited indicator, but the market growth is much more relevant. This strong growth trend is today technologically limited both related to the in-vehicle aspects and development aspects.

Unfortunately, current tools often do not provide enough integration to effectively support the large-scale industrial development process. There are however strong building blocks that relate to these needs, including OpenModelica for multi-domain cyber-physical system modeling, simulation and optimization based on the Modelica modeling language and the FMI standard; AUTOSAR and EAST-ADL allow software and system architectures to be captured along with related engineering information, as a basis for the required integrated engineering support.

Embedded software is an enabler for autonomous, electrified and connected vehicles, but several impediments are limiting its full potential. The goal of this project was to enhance the development process for automotive embedded software and to enable novel technologies for vehicle monitoring and control.

Several areas were identified as critical and thus in focus for the EMISYS project:

- Simulation technologies to allow virtual integration and simulation of cyber-physical systems at the drawing table and as an integral part of the software factory development pipelines.
- Systematic and Efficient handling of variability and product lines
- Efficient deployment of model based controllers onto embedded targets

4 Syfte, forskningsfrågor och metod

The purpose of the project was to research aspects in the development and integration of software components with cyber-physical components.

The research questions we addressed are:

1. How can co-simulation of software control and physical component simulation be integrated? What are the pros and cons of this approach?
2. How can the variability and fidelity of the components can be modeled using current languages and tools for cyber-physical modeling and simulation?

The research conducted in this project mainly used the design science paradigm rooted in engineering as our research method. Design science research is an iterative process consists of formulating questions, describing the problem, designing the solution, developing software prototypes that will solve the given problem, and evaluating the solution in order to find out whether the produced prototype solved the given problem.

Several research topics concerning aspects in the development and integration of software components with cyber-physical components have been covered:

- Pros and cons on the splitting of the cyber-physical system into several FMUs for co-simulation (D4.1)
- Handling of variability and fidelity (D3.1)
- Code generation and integration with FMI and eFMI (D2.1 and D4.1)
- Use cases and testing (D5.1)

The following deliverables are available for the project:

- D1.1 Requirements of an integrated Modelling, Configuration and Simulation Environment
- D2.1 eFMI enhanced code generation for Volvo Trucks needs
- D3.1 Model variant and fidelity handing in M&C&S
- D4.1 Efficient simulation of whole subsystems and vehicle models
- D5.1 EMISYS Demonstrators
- D6.1 EMISYS Tool Platform

5 Mål

The project goals and their status is given below:

- A modeling, configuration and simulation framework (M&C&S) supporting composition of FMUs/eFMUs and efficient simulation of integrated large-scale vehicle subsystems.
- Enhancement of the Volvo Trucks Eclipse-based software, based on the AUTOSAR and EAST-ADL architecture modeling representation, integrated with the abovementioned M&C&S framework.
- Evaluation for Volvo Trucks needs of the new eFMI open standard, (FMI for Embedded Systems, developed in the EMPHYSIS project).
- Enhancement and evaluation for Volvo Trucks needs of the new code generation techniques primarily developed in the EMPHYSIS project.
- Whole vehicle subsystem demonstrator, with multiple ECUs, buses, vehicle physical components, modeled as connected FMI/eFMI components together with regular AUTOSAR software components.

6 Resultat och måluppfyllelse

6.1 Overview

The project goals have largely been addressed and important results were developed. Below we summarize these per goal.

- A modeling, configuration and simulation framework (M&C&S) supporting composition of FMUs/eFMUs and efficient simulation of integrated large-scale vehicle subsystems.

The project has developed a prototype framework based on EAST-ADL and Modelica open source tooling.

- Enhancement of the Volvo Trucks Eclipse-based software, based on the AUTOSAR and EAST-ADL architecture modeling representation, integrated with the abovementioned M&C&S framework.

Evolution and adjustments have been made, but due to resource constraints, only on a small scale.

- Evaluation for Volvo Trucks needs of the new eFMI open standard, (FMI for Embedded Systems, developed in the EMPHYSIS project).

The standard has been theoretically investigated and assessed, but the practical experiments were not made. This was both due to lack of resources and because of missing tooling and technology for eFMI experiments. Feedback on the eFMI approach has been provided to the eFMI consortium and EMPHYSIS project.

- Enhancement and evaluation for Volvo Trucks needs of the new code generation techniques primarily developed in the EMPHYSIS project.

This goal was not addressed because of lack of open source tooling available.

- Whole vehicle subsystem demonstrator, with multiple ECUs, buses, vehicle physical components, modeled as connected FMI/eFMI components together with regular AUTOSAR software components.

Instead of the intended larger example, multiple, simpler demonstrator examples were used. This was due to lack of resources but also limitations of modeling and simulation technology,

6.2 Results per Goal

- A modeling, configuration and simulation framework (M&C&S) supporting composition of FMUs/eFMUs and efficient simulation of integrated large-scale vehicle subsystems

The project has developed a mature prototype framework based on EAST-ADL and Modelica open source tooling. The details of how the framework works are given below.

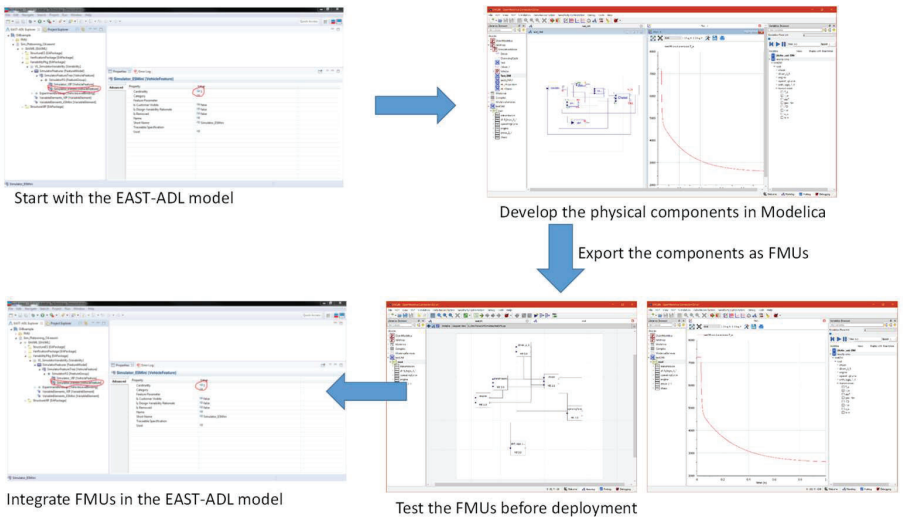

Figure 1. Map FMUs to physical components in the EAST-ADL model

In the developed framework one starts from a system EAST-ADL model defined in ArEATOP tool which contains both software and physical components. The physical components can then be constructed using modeling and simulation tools such as OpenModelica and then exported to FMU form. The FMUs are then mapped to the original components in the EAST-ADL model.

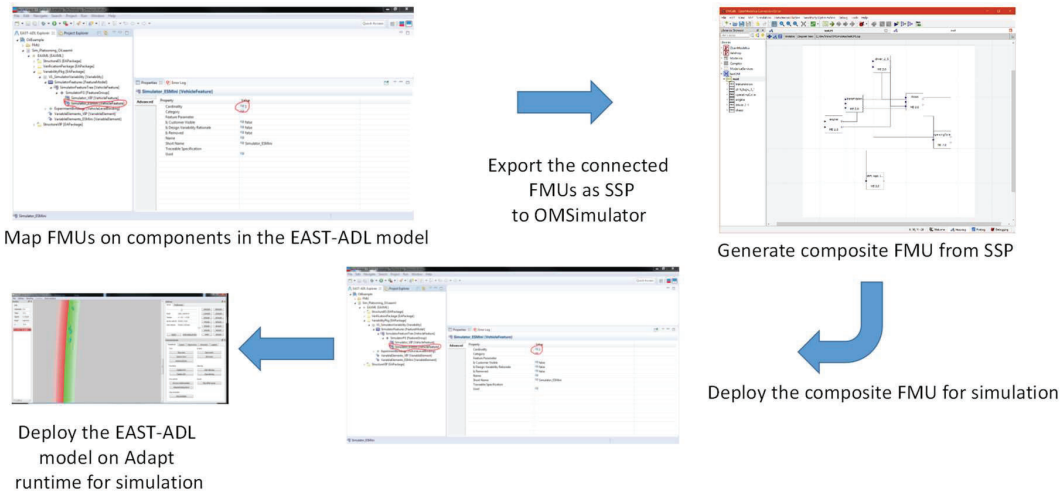

Figure 2. Generate composite FMUs and deploy them in Adapt runtime.

The EAST-ADL model contains connections between the software components and the physical components. The ArEATOP tool will split the physical components from the software ones and generate SSPs (composite FMU models) for them. Then from each of these SSPs, a composite FMU is generated using OMSimulator tool from OpenModelica. The final system is then deployed to the Adapt runtime which will run both the software components and the generated composite FMUs for the physical components.

The framework currently supports only FMUs and not eFMUs as there were no open-source tools available that supported eFMI in the project frame. However, the integration of eFMUs would be straightforward in the future when open-source tools supporting eFMI will become available.

- Enhancement of the Volvo Trucks Eclipse-based software, based on the AUTOSAR and EAST-ADL architecture modeling representation, integrated with the developed M&C&S framework

The ArEATOP software has been enhanced with support for SSP export version 1.0 to support the integration with the modeling and simulation tools. In general, evolution and adjustments have been made, but due to resource constraints, only on a small scale.

- Code generation and eFMI integration
  Evaluation for Volvo Trucks needs of the new eFMI open standard, (FMI for Embedded Systems, developed in the EMPHYSIS project)

The standard has been theoretically investigated and assessed, but the practical experiments were not made. This was both due to lack of resources and because of missing tooling and technology for eFMI experiments. Feedback on the eFMI approach has been provided to the eFMI consortium and EMPHYSIS project.

Currently there are no open-source tools that support generation of eFMI Galec (Generic Algorithm Execution Code) and production code. The OpenModelica team did not had enough resources in the EMPHYSIS project to develop such tools but it has developed support for eFMI equation code. This is a starting point for the needs represented by the EMISYS project goals. As there is interest in developing open-source eFMI tools for generation of Galec code, future projects can be created to will address further integration with the eFMI standard.

- Enhancement and evaluation for Volvo Trucks needs of the new code generation techniques primarily developed in the EMPHYSIS project

This goal could not be addressed as open-source eFMI tools were not available during the project.

- Whole vehicle subsystem demonstrator, with multiple ECUs, buses, vehicle physical components, modeled as connected FMI/eFMI components together with regular AUTOSAR software components

Instead of the intended larger example, multiple, simpler demonstrator examples were used. This was due to lack of resources but also limitations of modeling and simulation technology.

VehProp demonstrator

In the following we present the VehProp demonstrator, but more use-cases can be found in the D5.1 deliverable.

VehProp is a simulation model library for vehicle operation. Typically useful for comparing complete vehicle measures as energy or fuel consumption, transport efficiency, tire wear, etc. Comparisons in scope are different design of vehicles or different selection of vehicles. The report detailing the library can be found here.

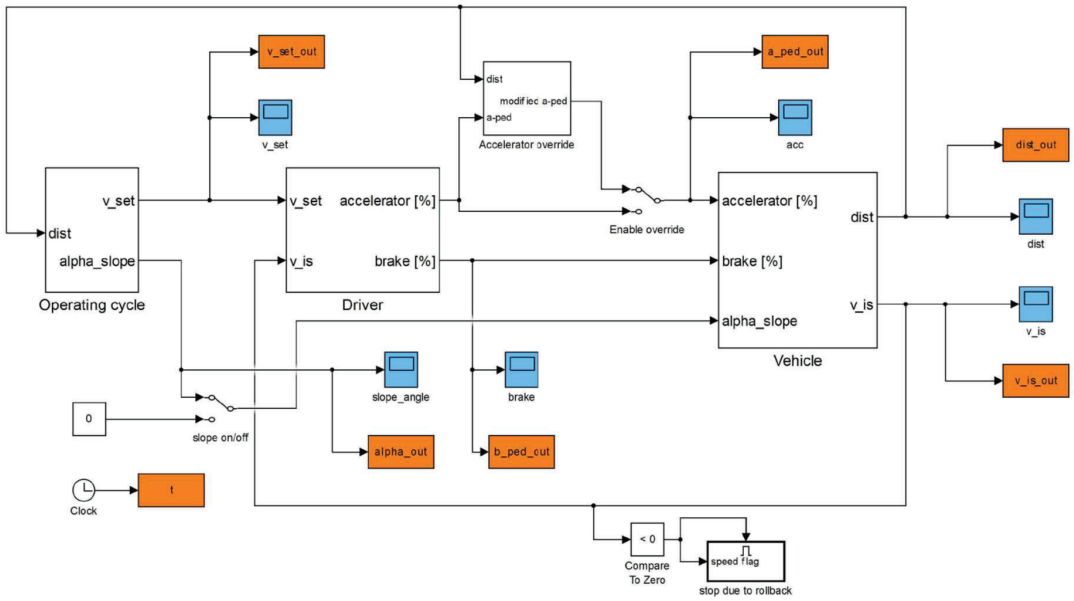

Figure 3. VehProp demonstrator - diagram

The Modelica model for the VehProp demonstrator was implemented by Chalmers and was further changed to be compatible with OpenModelica and more Modelica standard compliant. A simulation of the model is given below.

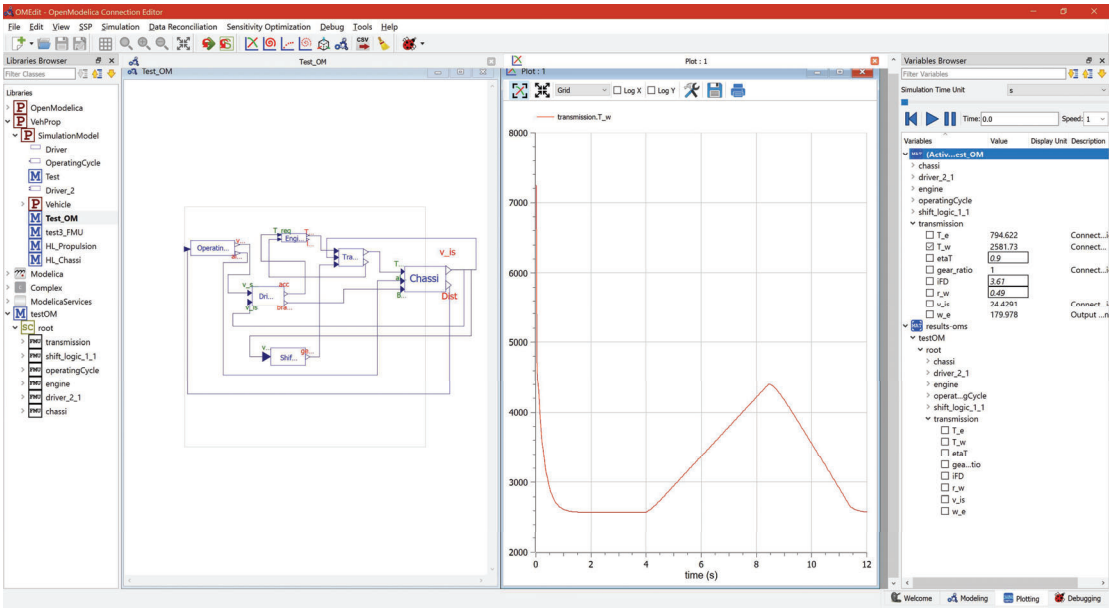

Figure 4. VehProp simulation in OpenModelica

The model was also modeled in ArEATOP as an EAST-ADL model.

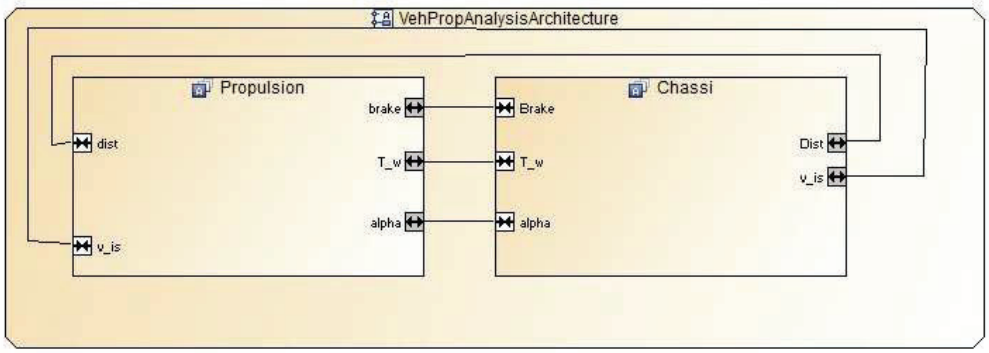

Figure 5. VehProp in ArEATOP

The Modelica model was split into several parts and for each an FMU was exported which was to be mapped to the components in the EAST-ADL model. The decomposition is given below.

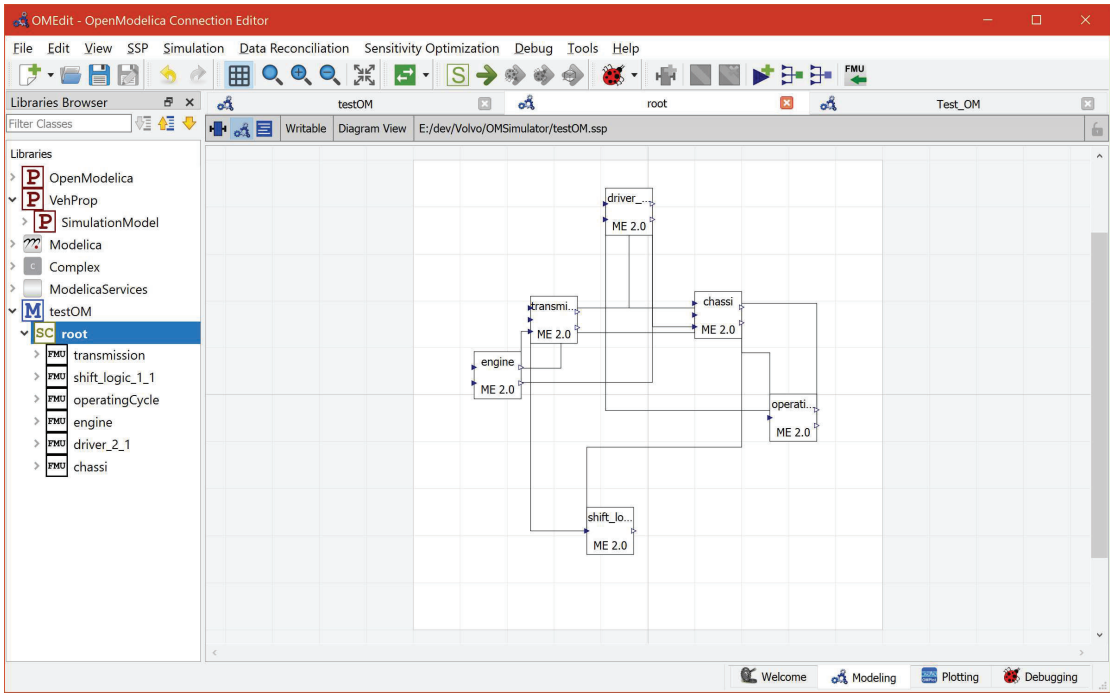

Figure 6. VehProp decomposed into FMUs and re-composed as a composite SSP model.

After the mapping the ArEATOP tool can export an SSP with the Plant model, made out of the connected FMUs. From this SSP the OMSimulator tool will generate a single FMU that can then be deployed to run in the Adapt runtime to simulate the complete system. A simulation result from Adapt is given below, demonstrating the consistency with continuous time simulation in Figure 3.

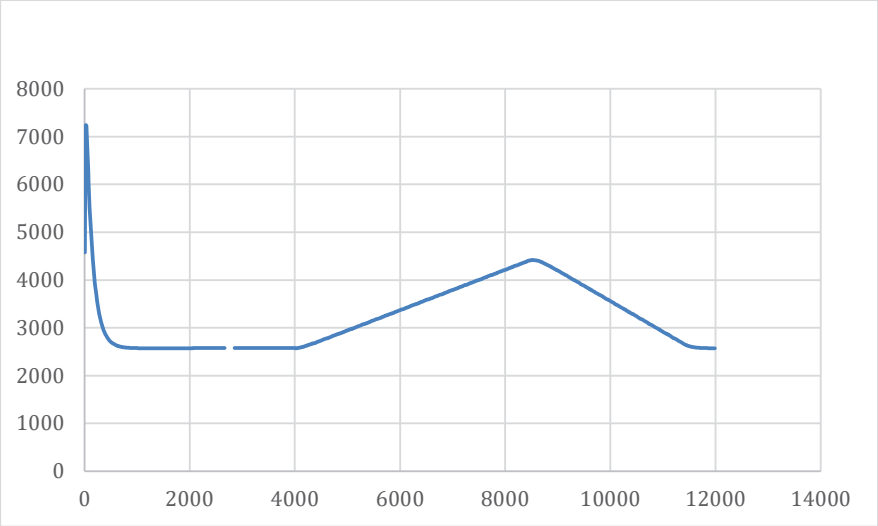

Figure 7. Simulation in the Adapt runtime

7 Spridning och publicering

7.1 Kunskaps- och resultatspridning

Hur har/planeras projektresultatet att användas och spridas?	Markera med X	Kommentar
Öka kunskapen inom området	X	The results of the project will be included in tutorials given at different conferences
Föras vidare till andra avancerade tekniska utvecklingsprojekt	X	Results from the project are part of public open-source frameworks
Föras vidare till produktutvecklingsprojekt		
Introduceras på marknaden		
Användas i utredningar/regelverk/ tillståndsärenden/ politiska beslut		

The project has interacted with several other projects and consortia

- EMPHYSIS – Embedded systems with physical models in the production code software. Feedback from EMISYS has been used in EMPHYSIS.
- EMBrACE - Environment for model-based rigorous adaptive co-design and operation of CPS. Results from EMISYS has been used in this project.
- OpenModelica – an open-source Modeling, Simulation, and Model- Based Development for Modelica with support for FMI and SSP. The cyber-physical system part of the framework developed in EMISYS is part of the OpenModelica project and will be maintained and further developed via OSMC (Open Source Modelica Consortium).
- EAST-ADL Association – The governing body of the EAST-ADL language. Results from EMISYS has been shared and discussed several times in the annual meeting of the association
- BUMBLE - Blandad grafisk och text-baserad modellering för förbättrad utveckling av komplexa system. EMISYS and BUMBLE has collaborated on the needs and evaluation of system modelling tooling.
- A-CPS - Automation in High-performance Cyber Physical Systems Development. A-CPS is leveraging on the EMISYS simulation technologies and aligned modelling approach.
- MoDev - Model-Based DevOps for Cyber-Physical System Product Lines. MoDev shares needs and concepts with EMISYS in the area of modelling product lines and variability.
- WASP industrial PhD project – Rigorous verification applied to continuous integration for autonomous vehicles. EMISYS has collaborated to investigate FMUs with Deep Neural Networks as a means to obtain plant models by training with field data.

The project has been disseminated also via:

- OpenModelica Workshop (2021) and ModProd Workshop (2018, 2020, 2022)
- Modelica Tutorial at various conference
- Open Source Modelica Consortium

7.2 Publikationer

Journal publications:

- Peter Fritzson, Adrian Pop, Karim Abdelhak, Adeel Asghar, Bernhard Bachmann, Willi Braun, Daniel Bouskela, Robert Braun, Lena Buffoni, Francesco Casella, Rodrigo Castro, Rüdiger Franke, Dag Fritzson, Mahder Gebremedhin, Andreas Heuermann, Bernt Lie, Alachew Mengist, Lars Mikelsons, Kannan Moudgalya, Lennart Ochel, Arunkumar Palanisamy, Vitalij Ruge, Wladimir Schamai, Martin Sjölund, Bernhard Thiele, John Tinnerholm, Per Östlund. The OpenModelica Integrated Environment for Modeling, Simulation, and Model-Based Development. Modeling, Identification and Control, 2020;41(4):241-295, November 2020, DOI https://doi.org/10.4173/mic.2020.4.1

Conference publications:

- Lennart Ochel, Robert Braun, Bernhard Thiele, Adeel Asghar, Lena Buffoni, Magnus Eek, Peter Fritzson, Dag Fritzson, Sune Horkeby, Robert Hällquist, Åke Kinnander, Arunkumar Palanisamy, Adrian Pop, Martin Sjölund. OMSimulator – Integrated FMI and TLM-based Co-simulation with Composite Model Editing and SSP. The 13th International Modelica Conference will be held at OTH Regensburg, Germany, March 4–6, 2019. DOI http://dx.doi.org/10.3384/ecp1915769

8 Slutsatser och fortsatt forskning

During this project an integrated prototype framework has been developed to support modeling, configuration and simulation of models based on EAST-ADL and Modelica open source tooling. Several research topics have been investigated:

- Pros and cons on the splitting of the cyber-physical system into several FMUs for co-simulation
- Handling of variability and fidelity
- Code generation and integration with FMI and eFMI
- Use cases and testing

As future research directions we plan to look into:

- Developing open-source tools for eFMI and FMI 3.0
- More examples to understand effects of model composition to large FMUs
- Extending the variability support
- Usability and user support aspects in tool chains

9 Deltagande parter och kontaktpersoner

Volvo Technology AB, (Volvo Group Trucks Technology)

Henrik Lönn <henrik.lonn@volvo.com>

RISE – Research Institutes of Sweden AB

Lennart Ochel <lennart.ochel@ri.se>

Department of Computer and Information Science, Linköping University

Adrian Pop <adrian.pop@liu.se>

Peter Fritzson <peter.fritzson@liu.se>