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The MegaM@Rt2 ECSEL Project

MegaModelling at Runtime – Scalable Model-based Framework for Continuous Development and Runtime Validation of Complex Systems

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Abstract

A major challenge for the European electronic industry is to enhance productivity by ensuring quality of development, integration and maintenance while reducing the associated costs. Model-Driven Engineering (MDE) principles and techniques have already shown promising capabilities, but they still need to scale up to support real-world scenarios implied by the full deployment and use of complex electronic components and systems. Moreover, maintaining efficient

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traceability, integration, and communication between two fundamental system life cycle phases (design time and runtime) is another challenge requiring the scalability of MDE. This paper presents an overview of the ECSEL¹ project entitled “MegaModelling at runtime – Scalable model-based framework for continuous development and runtime validation of complex systems” (MegaM@Rt2), whose aim is to address the above mentioned challenges facing MDE. Driven by both large and small industrial enterprises, with the support of research partners and technology providers, MegaM@Rt2 aims to deliver a framework of tools and methods for: 1) system engineering/design and continuous development, 2) related runtime analysis and 3) global models and traceability management. Diverse industrial use cases (covering strategic domains such as aeronautics, railway, construction and telecommunications) will integrate and demonstrate the validity of the MegaM@Rt2 solution. This paper provides an overview of the MegaM@Rt2 project with respect to its approach, mission, objectives as well as to its implementation details. It further introduces the consortium as well as describes the work packages and few already produced deliverables.

Keywords: Model-Driven Engineering, Design Time, Runtime, Megamodeling

1. Introduction

In the global context, the European electronic industry faces stiff competition. Electronic systems are becoming more and more complex and software intensive [1], which calls for novel engineering practices to tackle advances in
5 productivity and quality of these, now, cyber-physical systems [2].

Model-Driven Engineering (MDE) refers to a system development methodology where abstractions—or models—are systematically used along the process [3]. MDE promises many potential benefits (e.g., gains in productivity, portability, maintainability or interoperability) and several studies have been

¹<http://www.ecsel-ju.eu/web/index.php>

10 conducted to support these claims with empirical data [4–9]. Moreover, in the
last years, the technological ecosystem around MDE has flourished, providing
developers with a plethora of tools to support modeling tasks, ranging from
model management solutions to model transformation and code-generation en-
gines. However, these technologies need to be further developed to scale for
15 real-life industrial projects and provide advantages at runtime. The ultimate
objective of enhancing productivity by ensuring quality of development, integra-
tion and maintenance while reducing the associated costs can be achieved by the
use of techniques that integrate design and runtime aspects within system en-
gineering methods incorporating existing engineering practices [10]. Industrial
20 scale models, which are usually multi-disciplinary, multi-teams, combine several
product lines and typically include strong system quality requirements, can be
exploited at runtime by advanced tracing and monitoring. Thus, achieving a
continuous system engineering cycle between design and runtime, ensuring the
quality of the running system and getting valuable feedback from it that can be
25 used to boost the productivity and provide lessons-learnt for future generations
of products [11].

A major challenge in the Model-Driven Engineering of critical software sys-
tems is the integration of design and runtime aspects. The system behavior at
runtime has to be matched with the design in order to fully understand critical
30 situations, failures in design, and deviations from requirements. Many meth-
ods and tools exist for tracing the execution and performing measurements of
runtime properties (see e.g. [12][13]). However, most of these methods do not
allow the integration with system models – the most suitable level for system
engineers for analysis and decision-making.

35 The MegaM@Rt2 (MegaModelling at Runtime) proposal was submitted to
the ECSEL in 2015. It received good evaluation scoring: 4.3 in Excellence,
4.6 in Impact and 4 in Implementation. The overly positive and instructive
remarks motivated us to continue with MegaM@Rt2 in 2016, and a proposal
was submitted for the research and innovation action in the call H2020-ECSEL-
40 2016-RIA, by reinforcing the consortium and clearing the project details. The

project officially started on April 1, 2017 and runs for 3 years.

The vision of MegaM@Rt2 is to create a scalable framework for model-based continuous development and validation of large and complex industrial systems by exploiting important features of:

- 45 • MARTE, SysML, and others, to express both system functional and non-functional properties;
- model-based verification and validation methods at design time and run-time;
- methods for model management/megamodelling;
- 50 • methods for traceability over large multi-disciplinary models;
- methods for inference of system deviations from expected behavior and affected design elements.

This article is an extension of our previous conference paper [14]. Compared to it, we have added many details on the current status of the project as well as the already produced deliverables. At the time of this submission, the project is about to enter its second year of activity. So far, industrial case study requirements and the baseline methodologies provided by the project partners have been collected and analyzed in the context of Work Package 1 (WP1). In addition, a detailed study of the state-of-the art has been performed and corresponding needs for innovation have been identified as part of Work Packages 2, 3 & 4 (WP2–4). In the upcoming phase of the project, we will perform gap analysis between the industrial needs and the baseline methodologies & tools. Moreover, we will suggest the main features of the MegaM@Rt2 framework as well as a related road map presenting how the different components will be further developed.

65 Section 2 outlines the mission and the objectives of MegaM@Rt2. Section 3 discusses the main concepts of the development approach proposed by the project. The potential industrial impact of MegaM@Rt2 is summarized in

Section 4. The partners of the consortium are presented in Section 5. The
70 work packages (WPs) aiming at achieving the objectives of MegaM@Rt2 are
presented in Section 6, whereas Section 7 presents a brief description of each
WP along with briefly describing some already produced deliverables. Section 8
concludes the paper.

2. Project Mission and Objectives

75 The mission of MegaM@Rt2 is to create a framework incorporating meth-
ods and tools for continuous system engineering and validation leveraging the
advantages of scalable model-based methods. This will provide benefits in signif-
icantly improved productivity, quality and predictability of large and complex
industrial systems. Such a mission is realized through the following specific
80 objectives:

- **Objective 1.** *MegaM@Rt2 continuous system engineering:* to develop
scalable methods and tools for the integration of design artifacts result-
ing from heterogeneous engineering practices, including the modelling of
functional and non-functional properties (e.g. performance, energy con-
85 sumption, security and safety) based on requirements.
- **Objective 2.** *MegaM@Rt2 runtime analysis:* to develop integrated meth-
ods and tools for trace analysis based on probes injection to runtime arti-
facts, as well as improved monitoring in order to validate the system-level
requirements.
- 90 • **Objective 3.** *MegaM@Rt2 (global) model management:* to develop scal-
able infrastructure for efficient handling and management of numerous,
heterogeneous, and large models potentially covering several functional
and non-functional aspects.
- **Objective 4.** *MegaM@Rt2 unified traceability management:* to develop
95 holistic traceability methods and tools 1) able to link and manage models
and their elements from different tools as well as 2) suitable for large

distributed cross-functional working teams and 3) allowing to integrate the feedback to the system level models.

- 100 • **Objective 5.** *MegaM@Rt2 demonstrators validation:* to develop specific demonstrators and validate MegaM@Rt2 technologies through 9 complementary industrial case studies.
- **Objective 6.** *MegaM@Rt2 market uptake:* to prepare exploitation of the MegaM@Rt2 technology through open source and commercial tools.

3. Concept and Approach

105 In the past, MDE principles and techniques have already shown promising capabilities that have been experimented in a context having software components relying on hardware configurations and their interactions e.g., with their underlying environment, being very often numerous, complex, heterogeneous and strongly interrelated. However, they have generally failed in terms of 1) scalability to support real-world scenarios implied by the full deployment and use of complex electronic components and systems (ECS) and 2) maintaining efficient traceability, integration and communication between two fundamental system life-time phases which are design time and runtime, notably as far as non-functional properties and their verification & validation aspects (see e.g. [15][16])
110 are concerned.
115

As a consequence, the overall idea of MegaM@Rt2 is to scale up the use of model-based techniques by offering proper methods and related tooling, interacting with both design time and runtime, as well as to validate the designed and developed approach in concrete industrial cases involving complex ECS. To this
120 intent, MegaM@Rt2 proposes an overall model-based approach combining existing and novel techniques. A fundamental challenge notably resides in providing efficient traceability support between the two levels i.e., from design models to runtime ones and back. Moreover, modern large-scale industrial software engineering processes require thorough configuration and model governance to

125 provide the promised productivity gains. Thus, a scalable megamodeling ap-
proach is required to manage all the involved artifacts e.g., the many different
models, corresponding work flows, configurations, etc. and to better tackle their
large diversity in terms of nature, number, size, complexity, etc. Verification
and validation of highly configurable systems thus also takes importance (see
130 e.g. [17]).

To cover all these topics and deal with the complete value chain, MegaM@Rt2
brings together prominent tool vendors and research organisations with state-of-
the-art methods and tools to be validated in highly relevant European industrial
case studies. The end users from the space, naval, railway, smart grid, smart
135 warehouse and telecom industry domains aim to drive the project by providing
real-world requirements and case studies as well as by validating and endorsing
the MegaM@Rt2 results.

Figure 1 provides an overview of the MegaM@Rt2 global approach and em-
phasizes its key principles and concepts, relating them to the corresponding
140 work packages (described in detail in Section 6). A set of current engineer-
ing practices based on SysML, AADL, EAST ADL, but also Matlab/Simulink,
AUTOSAR and Method B or Modelica, each one producing a set of specific de-
sign models, requirement specifications and resulting software (and sometimes
also hardware) artefacts, are integrated into a global system model providing a
145 complete view of the cyber-physical system, and detailing the components, be-
haviour and desired quality properties of the system. These properties are then
object of exhaustive continuous testing and monitoring in the runtime environ-
ment (thanks to the configuration of the target platform and the injection of
probes in the software or also in the hardware [18][19][20]) to detect deviations
150 in real-time. These deviations, plus all the traces information collected in the
process, are analyzed to detect the impacted components in the integrated view
of system models. When possible, automatic repairing recommendations will be
provided to correct the identified issues and reconfigure or redeploy the system
to start the next iteration of the continuous integration process.

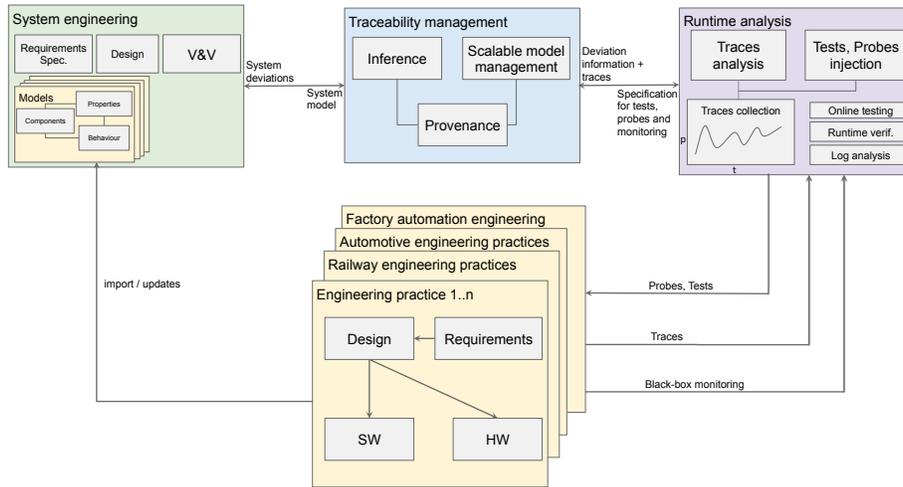


Figure 1: The MegaM@Rt2 Overall Approach.

155 **4. Industrial Impact**

The ECSEL² program seeks to invest in projects that strengthen the industrial competitiveness, enable economic growth and improve sustainability. Europe has a reasonably strong position in the world embedded market (30%), but this is falling as other geographies grow – some at the vanguard and others catching up. The MegaM@Rt2 consortium argues that investment in capability of the software development tools market, although only a fraction, has a very large pay-off. We have seen that the software component of the systems is increasingly more growing in importance. As the hardware becomes commoditized, the added value will rapidly shift to the software. Achieving technological and competitive superiority in software development tools will allow European firms to participate with greater dominance in the overall software market.

Specifically, MegaM@Rt2 achieves this in part through reducing development and exploitation costs and in part by allowing mastery of more complex systems. Reducing development costs and time-to-market is a competitive ad-

²<http://www.ecsel-ju.eu/web/index.php>

170 vantage, allowing on, one hand, greater innovation in each product and allowing
faster reaction to hardware changes or new usage scenarios on the other. As
the Cyber-Physical Systems' world evolves, the agility to react rapidly to new
opportunities is a critical success factor for businesses. Mastering ever more
complex systems allows new usage scenarios to emerge, based on optimization
175 of greater problems or more optimized solutions for existing ones.

Improved software will allow the bigger players to better position their over-
all solutions and engender small businesses fulfilling niche needs for high end
bespoke software. Investment in this area is timely and appropriate. The small
scale and the under-developed capacity of this market segment can lead to large
180 pay-offs in the related fields, whereas the overall embedded systems are of such
a magnitude that it requires vast research investment for significant progress.

The MegaM@Rt2 objectives address several market trends in Cyber-Physical
Systems:

- Increasing inclusion of advanced techniques like model-based design, de-
185 velopment and validation.
 - MegaM@Rt2 supports this trend in the technologies provided through
industrial case studies.
- Technology availability and support during extended period (e.g., up to
30 years in the railways).
 - 190 – MegaM@Rt2 open source solutions support this requirement.
- Convergent combination of multi-domains industrial practices.
 - MegaM@Rt2 supports this challenge with multi-domain case studies.
- More and more complex (structure/behaviour) connected systems.
 - With a clear support for megamodelling and system analysis at run-
195 time, MegaM@Rt2 supports this trend.

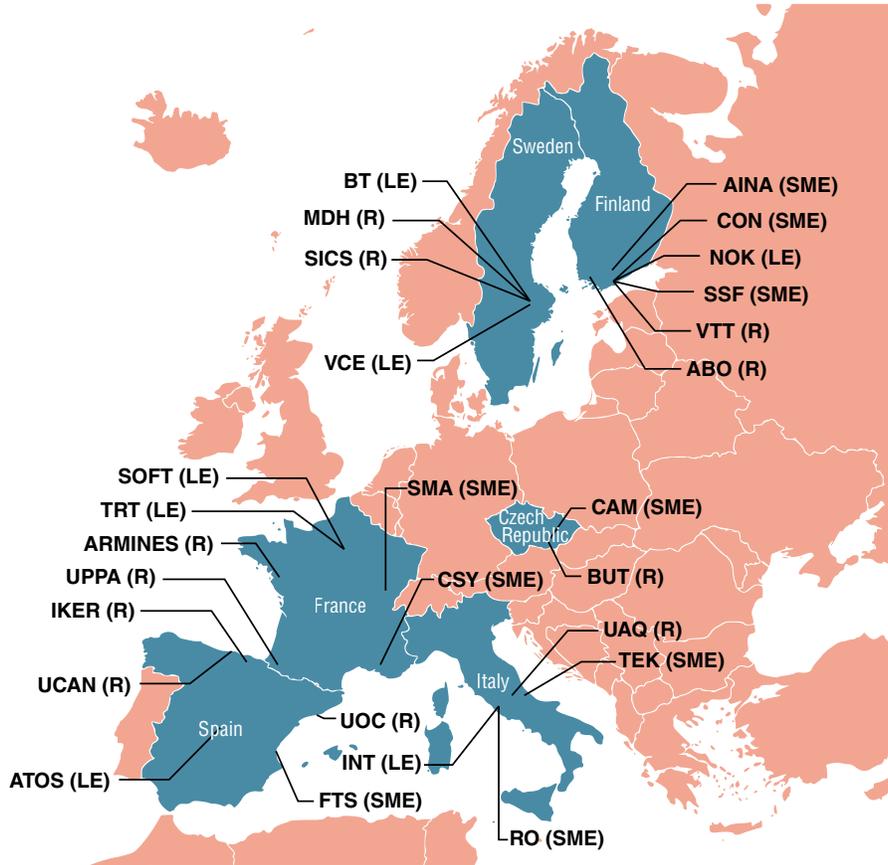


Figure 2: The MegaM@Rt2 Consortium.

5. Consortium

The MegaM@Rt2 consortium is large and is composed of partners having different complementary profiles. It brings together 27 partners coming from 6 European countries, each of which constitutes a national consortium (France, Spain, Italy, Sweden, Finland and Czech Republic). See Figure 2 (the abbreviations used in partner names are described in Sections 5.1, 5.2, 5.3).

The project consortium is strongly industry-led and consists of 7 Large Enterprises (LE) and 9 Small and Medium Enterprises (SME) accompanied by 11 universities or research and technology transfer organizations (R). An adequate

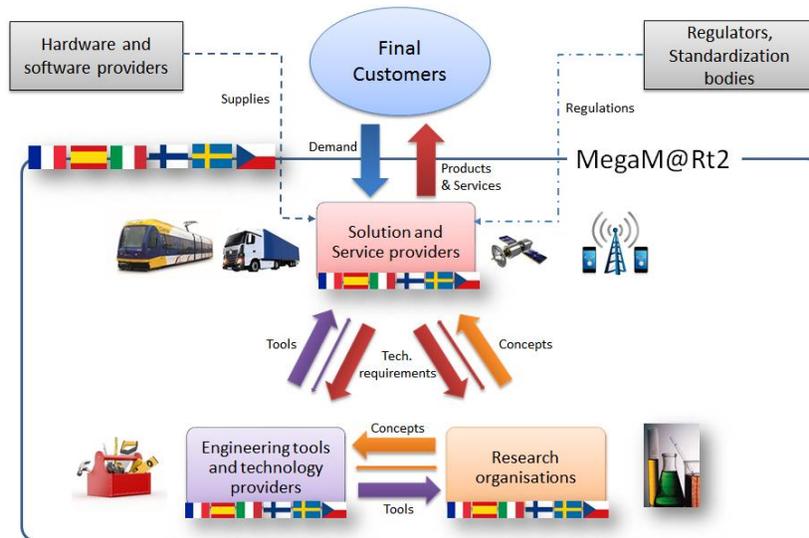


Figure 3: The MegaM@Rt2 project involves partners covering the market and technology value chains.

205 level of balance has been achieved by choosing SOFTEAM as a technical coordinator (a French LE with comprehensive experience in managing large research projects) while the managerial coordination is led by Mälardalen University (Sweden), which also has an extensive experience in both, participating and managing, EU projects. A suitable management strategy has been evolved by
 210 bringing together partners that know each other and have already collaborated in the past [21]. To setup the consortium, a complete value-chain has been taken into account by selecting case study owners, technology providers, and research partners (Figure 3):

- **Case study owners and end-user partners.** Providing knowledge of
 215 both end-users needs and development scenarios for complex industrial systems.
- **Technology and service providers partners.** Providing knowledge and tools in MDE, hardware and software synthesis, collaborative modelling and standardization.

220 • **Research partners.** Providing knowledge in megamodelling, MDE, code generation, Verification & Validation and logs analysis.

In the remaining of the section, all the members of the consortium are briefly described with respect to their role in the project.

5.1. Case study owners and end-user partners

225 Nine industrial partners will play the role of case study providers and end-users as described below.

Thalès Research & Technology – TRT (FR) provides a case study in avionics domain and will lead the validation scenarios definition. TRT has an extensive experience with MDE.

230 **ClearSy System Engineering – CSY (FR)** provides a case study in safety critical railway systems.

IKERLAN S. Coop – IKER (ES) provides a case study in smart warehouse domain and will lead the experiments with baseline technologies.

235 **Tekne – TEK (IT)** provides a case study in short-range communications domain and will lead the requirements analysis activities.

Nokia – NOK (FI) provides a case study in the telecommunications domain and will lead the case studies development activities.

Bombardier Transportation Sweden AB – BT (SE) provides a case study of their train control and management system (train/railway domain).

240 **Volvo Construction Equipment AB – VCE (SE)** provides a case study in the vehicular domain (VCE’s electrical and electronic system technology platform).

Camea – CAM (CZ) provides the case study in vision-based intelligence.

245 **AinaCom Oy – AINA (FI)** will provide a case study in the communication gateway domain.

The technological domains and the application areas of the case studies in the project are summarized in Table 1.

Table 1: Case studies from MegaM@Rt2 Partners.

No.	Technological Domain	Application specific
1	Avionics	Flight Management System
2	Railway	Platform Screen Doors Control
3	Smart warehouse	Deployment and Supervision of Agents
4	Short range communications	Indoor Positioning
5	Telecommunications	Base Transceiver Station
6	Transportation	Train Control and Management System
7	Automotive	Engine Control
8	ICT Services	SMS Gateway
9	Traffic monitoring	Intelligent Traffic Surveillance System

5.2. Technology and service providers partners

Eight industrial partners will play the role of technology and service providers
as described below.

Softteam – SOFT (FR) will contribute with its expertise in MDE as a tool
vendor for Modelio work bench and as an active member of the Object
Management Group. SOFT’s technical contribution will include the work on
user interface generation from Interaction Flow Modeling Language (IFML)
specification, code generation with “MDD+aspects” approach and scalable
model management with model fragments infrastructure.

Smartesting Solutions & Services – SMA (FR) will lead the work package
on runtime methods and tools. SMA’s main contribution will be in online
testing techniques development. SMA will contribute to baseline technolo-
gies with SmartTesting CertifyIt technology.

ATOS Spain – ATOS (ES) will lead the MegaM@Rt2 framework integration
and the exploitation work package. ATOS will contribute to model simula-
tion task force and code generation by providing development for Founda-
tional UML (fUML) and AspectJ.

265 **Fent Innovative Software Solutions – FTS (ES)** expertise is focused on
the development of execution platforms for mixed criticality systems. It is
specialized in: (1) Design and development of hypervisor technology; (2)
Design and development of real-time operating systems; (3) Adaptation of
operating systems to be executed as a partition on top of XtratuM hypervi-
270 sor. FTS will mainly be involved in Runtime work package and will provide
its expertise in execution platforms.

Intecs – INT (IT) contributes to the MegaM@Rt2 framework with the CHESSE
model-driven, component-based methodology and tool chain for the de-
velopment of high-integrity systems for different domains. INT partici-
275 pates in the development of the CHESSE open source project delivered under
Eclipse/Polasys. CHESSE relies on MARTE, with focus on non functional
properties modelling, analysis and correct-by-construction code generation.

Ro Technology – RO (IT) will provide advanced design, development and
V&V Techniques.

280 **Space Systems Finland Ltd. – SSF (FI)** will contribute to the MegaM@Rt2
framework with the LIME toolset for runtime monitoring of the implemen-
tations and automatic test generation, which was partially funded by SSF.
SSF will work on integrating the toolset to other MegaM@Rt2 tools. SSF
will also participate in the application of the tools to the case studies pro-
285 vided by other Finnish partners. Additionally, SSF will share its extensive
knowledge of verification and validation methods for safety-critical systems.

Conformiq Software Oy – CON (FI) will contribute to model-based func-
tional test generation in all stages of software process, and to model-based
test validation by functional coverage and test correctness analysis with re-
290 spect to system models. Conformiqs focus is in behavioural models in con-
trast to e.g. purely architectural models. Conformiq will work on integrating
the technology platform to other MegaM@Rt2 tools. In addition, Conformiq
will participate in the deployment and application of the platform to the case
studies.

Table 2: MegaM@Rt2 Research Partners.

Name	Contributions
Association pour la Recherche et le Développement des Méthodes et Processus Industriels / Institut Mines-Télécom – ARMINES (FR)	Leads activities on scalable model management & traceability.
Université de Pau et des Pays de l’Adour – UPPA (FR)	Leads activities on models’ execution techniques development and contribute with the PauWare library.
Universidad de Cantabria – UCAN (ES)	Leads development of the design level verification and validation methods tools. Contributes with eSSYN tool suite featuring software synthesis technology.
Universitat Oberta de Catalunya – UOC (ES)	Leads development of scalable model-based techniques. Contributes with EMFtoCSP verification tool suite.
Universit degli Studi dell’Aquila – UAQ (IT)	Leads the traceability and provenance task force.
Åbo Akademi University – ABO (FI)	Leads the runtime verification task and contributes to all the work packages providing expertise in Aspects Oriented Modelling. Further contributes with UPAAL TRON tool suite.
Teknologian tutkimuskeskus VTT Oy – VTT (FI)	Leads development activities in logs analysis with machine learning and data mining technologies.
RISE SICS Västerås AB Västerås – SICS (SE)	Contributes in runtime verification and validation methods, their implications and required support from higher modelling levels.
Mälardalen University – MDH (SE)	Contributes in verification and validation at design-time, verification and testing at run-time, integration of megamodeling and traceability within the overall tool chain.
Brno University of Technology – BUT (CZ)	Contributes in runtime model optimization and validation through classification and scheduling methods from historical performance data.

295 5.3. Research partners

Ten partners will drive the research activities of the consortium. Their names and contributions in the project are summarized in Table 2.

6. Work Packages

The main expected result of MegaM@Rt2 is a practical framework incorporating methods and tools for continuous system engineering and validation. 300 As introduced earlier, its overall goal is to leverage the advantages of scalable model-based methods to provide significantly improved productivity, quality and predictability of large and complex industrial systems. This framework

will be composed of three main tool sets for 1) system engineering/design &
305 continuous development, 2) related runtime analysis, and 3) global model &
traceability management (respectively). As a consequence, we have organized
the project around the research work and realization of these tool sets. Their
integration and actual application onto a set of concrete use cases, covering
different industrial domains, is also a central aspect of the project.

310 To reflect these principles, the project has been organized in 7 complemen-
tary work packages (WPs):

- WP1. Case Study Requirements Analysis & Architecture Specification;
- WP2. MegaM@Rt2 System Engineering;
- WP3. MegaM@Rt2 Runtime Analysis;
- 315 • WP4. MegaM@Rt2 Global Model & Traceability Management;
- WP5. Integration, Case Study Development & Evaluation;
- WP6. Dissemination and Exploitation;
- WP7. Management.

The work to be realized in the project is strongly requirements-driven. These
320 requirements are extracted from the use cases as part of WP1, by exploiting the
collaboration among the use case providers (mainly large industrial companies)
and the technical providers (composed of both service/product companies and
experienced researchers from academia). WP1 is also in charge of defining the
overall architecture (conceptual and technical) of the MegaM@Rt2 solution.
325 Most of the research and development effort is concentrated in WP2, WP3 and
WP4, which aim at providing the three tool sets previously mentioned. Within
WP5, these technical results will be then integrated together, applied on the use
cases and finally evaluated for further improvement. The work in the project
will follow an iterative and incremental approach divided into three consecutive
330 phases. In the first phase, we will specify the requirements, validation scenarios,

global architecture and roadmap. In addition, case study partners will experiment with baseline technologies while technology providers will develop the first set of prototypes. In the second phase, we will consolidate these prototypes, integrate them in a first release of the MegaM@Rt2 framework and run an initial set of validation scenarios. Based on the obtained results, in the third phase, we will integrate and validate the technical solutions, provide final validation and experience reports from the use cases (as well as a final management report). In parallel, the dissemination (academic or industrial, including the relation with the standardization organizations such as the Object Management Group, OMG) and exploitation (e.g., consortium and individual business plans) activities will be conducted in WP6. The general project management and reporting activities will be performed under the umbrella of WP7.

7. Work Package Descriptions and Deliverables

We will now present a brief description of each WP along with briefly describing some already produced deliverables.

7.1. WP1 - Case Study Requirements Analysis and Architecture Specification

This WP gathers the work on the case studies definition and requirements analysis (by end-users) with the global architecture and road map specification (by technology providers). The industrial partners will set real requirements for research and technology providers. They will closely collaborate and be integrated in the development teams, providing regular feedback on the elaborated technologies. This WP also concentrates on the validation scenarios, i.e. end-to-end demonstrators for the MegaM@Rt2 solutions in varied industrial contexts. End-users will develop methods for gathering the data needed for qualitative and quantitative verification of MegaM@Rt2 achievements. They will run the related experiments in a cost-efficient manner, and will provide representative evaluation of the technologies for large scale usage. From their side, the technology partners will define the architecture and a detailed road map for the technical developments.

360 7.1.1. *Examples of already produced deliverables in WP1*

Industry Requirements Specification: This deliverable marks the first step of activities for the MegaM@RT2 case study providers. They have defined the case studies to be developed during the project, exposed their current practices, organized the capabilities of the MDE framework they plan to use
365 according to development scenarios, and mapped such scenarios on the time line of the project execution.

On the basis of all above, the case study providers have expressed their end-user requirements for the improved MDE framework that MegaM@RT2 aims to provide. This deliverable is also the first step of the collaboration between the
370 case study providers and the technology providers. This deliverable is also an input to the roadmap development of the MegaM@Rt2 framework, where the capabilities of the baseline tools will be matched to the requirements from the case study providers.

A total of 9 case study providers have given their concrete requirements and
375 their expectations from the MegaM@Rt2 framework (Table 1).

Architecture Specification and Roadmap: This deliverable defines the initial vision of the global architecture of the MegaM@Rt2 framework. As a starting point, we have described the conceptual tools as well as the individual tools by partners. The initial version of the deliverable has concentrated on the
380 following aspects:

- *High-level requirements* to identify the features, goals and objectives of each tool component. These technology requirements will serve as the starting point for the ongoing refinement, elicitation and traceability work that links the tools and methods development with case study develop-
385 ment.
- *Functional interfaces* that define the high-level services of the tools as well as the integration points. We took attention to extract common interfaces with the goal to match the tools that may easily collaborate.
- *Subordinates* that are high-level parts of the tool components that help to

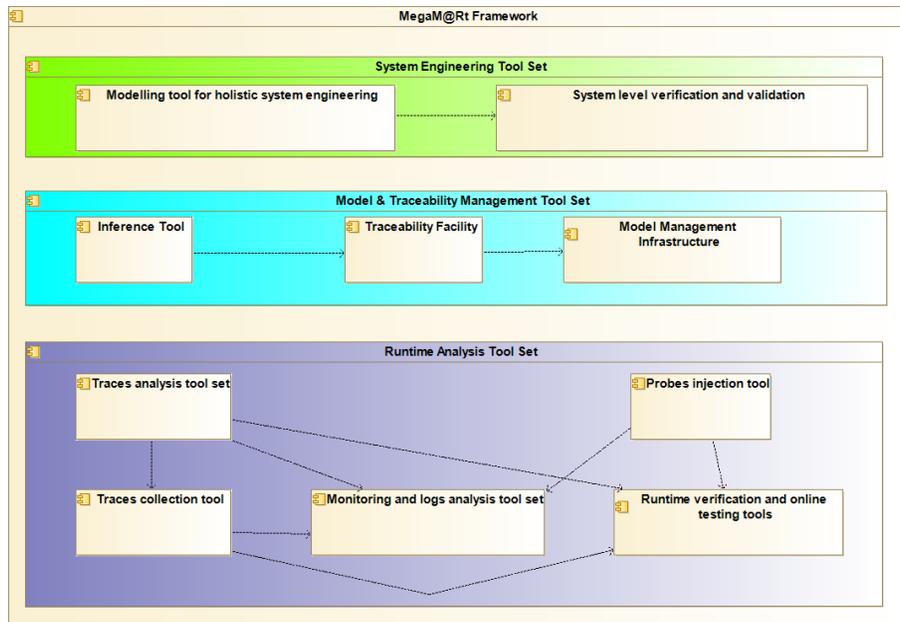


Figure 4: MegaM@Rt2 Framework Architecture Overview

390 understand better the tool functionality.

- *Deployment* to refer the deployment platforms by paying attention to extract the commonalities that would help to identify the facility for an integrated solution.

We have selected Modelio as the common platform for architecture modelling, primarily because SOFTEAM (MegaM@Rt2 technical leader) is an active contributor to Modelio development and has all the technical and support means to help partners to model in a productive way. Figure 4 shows a high-level architecture of MegaM@Rt2 framework in Modelio. The modeled framework regroups several interconnected tool sets including tool sets for *Holistic System Engineering*, *Model and Traceability Management* as well as for *Runtime Analysis*.

7.2. WP2 - MegaM@Rt2 System Engineering

This WP gathers the activities related to the definition of the required Domain Specific Languages (DSLs) to support model-based system design, and
405 of the methods and tools to develop integrated system models. One of the strongest points of model-based approaches lies in the support for separation of concerns and definition of specific architectural views. Specific views focus on specific areas of the development from system to software level, including the system functional, logical and physical decomposition, identification of software
410 and hardware components, definition of functional and non-functional properties, software architecture, data, behavior and algorithmic modeling. This WP concentrates on all the modelling and tooling aspects of MegaM@Rt2. The goal is first to provide the foundations for WP3 and WP4, and later, to design, develop and support the MegaM@Rt2 system engineering tool set to be used by
415 industrial partners in WP5.

7.2.1. Example of already produced deliverable in WP2

Foundations for Model-driven Design Methods: This deliverable provides the foundations for the design of the MegaM@Rt2 tool chain. Its objective is to analyse the state-of-the-art in terms of both research approaches and existing
420 modelling solutions and tools in the context of model-based continuous development. Within this task, relevant existing DSLs and modelling technologies have been identified and presented, and the possibilities for their utilization, extension and/or integration within MegaM@Rt2 have been analysed. The objective is to provide an overview of the current state of practice, and define
425 the concepts, features and principles that will be the basis for the development of the MegaM@Rt2 design solutions. In particular, the foundation for models, DSLs and their semantics have been addressed. The content of the deliverable has been organized around three main topics: (i) Systems Modelling, (ii) Verification and Validation and (iii) Modelling Methodologies. The first one focuses
430 on standard modelling languages and DSLs, state-of-the-art modelling tools and environments, and methodologies towards the participatory development

of DSLs. The second topic covers automatic or semi-automatic solutions for the verification and validation of MDE artefacts (e.g., models, transformations). Finally, the third topic covers different state-of-the-art modelling methodologies. 435 The deliverable ends with a comprehensive catalog of the solutions offered by the different tool providers to all the other members of the consortium. For further information, interested readers can access the full text of the deliverable from the project website³.

7.3. WP3 - MegaM@Rt2 Runtime Analysis

440 This WP focuses on the usage and definition of models at runtime level, and on the associated techniques or methods. Models at runtime can be designed or obtained from the system itself. For instance, logging or monitoring the system under the form of models can be performed jointly with the system execution and can help in ensuring a correct system execution. Afterwards, 445 such models can also be analyzed to enhance design models from WP2 and are thus entries of the tools and methods of WP4. Verification and validation issues can be managed directly at runtime, enabling the detection of problems that can be solved at runtime or propagated back to design level. This can be achieved by checking the expected behavior according to functional and non- 450 functional properties embedded in the design models, or by analyzing jointly runtime models with the actual system execution to determine if the system fulfills its specifications. To this intent, this WP will notably provide on-line testing and verification techniques.

7.3.1. Example of already produced deliverable in WP3

455 **Foundations for Model-Based Runtime Methods:** This deliverable provides a succinct overview of the foundations of model-based runtime methods and technologies in order to support the innovation tasks of WP3 of the MegaM@Rt2 project.

³<http://hdl.handle.net/20.500.12004/1/P/MMART2/D2.1>

The deliverable discusses how runtime artifacts are obtained from design
460 artefacts and from execution logs. In the first category, we overview approaches
for generating run time code and models from design models via code generation
and, respectively, model transformations. In the second category, we discuss
approaches for creating or improving the runtime artifacts by analyzing the
runtime execution logs of the system via methods like machine learning and
465 data analytics.

We also discuss how runtime artifacts are used at runtime either by executing
them as part of the system at runtime or by using them to generate tests or
monitor the system during its operation.

Throughout this deliverable, we have scrutinized the state-of-the art, the
470 state-of-practice, and the baseline technologies which are available for the project
participants. To this extent, the deliverable has investigated current methods
and tools for their benefits and existing limitations. The results of this deliver-
able are meant to lay the basis for defining new concepts, methods and tools for
coping with these limitations and successfully deploying runtime methods to in-
475 dustrial settings. This deliverable also provides input for the specification of the
MegaM@Rt2 runtime tools to support automated code generation and model
execution, log analysis, runtime verification and testing activities. The deliv-
erable also includes a collection of relevant solutions and tools provided by the
MegaM@Rt2 consortium members as baseline technologies in the project. For
480 further information, interested readers can access the full text of the deliverable
from the project website⁴.

7.4. WP4 - MegaM@Rt2 Global Model and Traceability Management

This WP focuses on megamodelling, also called global model management,
in which models for design time (WP2) and models for runtime time (WP3)
485 are to be managed and aligned all together. This relies on the base notion of a
megamodel [22], a model that intends to describe the metadata on the different

⁴<http://hdl.handle.net/20.500.12004/1/P/MMART2/D3.1>

models involved in a given engineering process, as well as the related inter-relationships and corresponding artifacts (transformations, generators, etc.). Such a (mega)model can be navigated and queried at any time in order to
490 retrieve or compute the required information, notably as far as traceability between models is concerned.

In the context of MegaM@Rt2, a particular focus is put on various scalability topics: not only the size of the models is larger, but there is also a larger number of model users with different roles; there are various kinds of languages (DSLs)
495 involved for different needs, including e.g. user interface (UI) related languages, and various transformations related to them. The second (and directly related) focus of this WP is on traceability between design time and runtime, as not in all cases the same model can be used for both purposes. WP4 also provides implementation of the tooling for scalable megamodeling/traceability and guidelines
500 for their deployment and practical use in case studies. WP4 is designed to deliver its results incrementally, notably by collecting progressively feedback on the developed features from their application to the project use cases. Figure 5 summarizes the focus of WP4.

7.4.1. Example of already produced deliverable in WP4

505 Foundations for Model Management and Traceability:

The main goal of WP4 is to elaborate on the required glue between the artifacts produced in WP2 (e.g., design models) and the ones produced in WP3 (e.g., runtime models). As a result, it is expected to provide a so-called global MegaM@Rt2 Model and Traceability Management framework to be a core part
510 of the MegaM@Rt2 overall solution and to be notably deployed on the projects use cases (among possibly others). As the initial step in WP4, this deliverable thus provides an overall state-of-the-art in terms of existing model management and traceability solutions. It presents the main common principles and approaches related to model storage, querying, handling and linking with others
515 models and modeling artifacts, notably via model views [23] and/or so-called megamodels [24]. It also describes the available traceability and interoperabil-

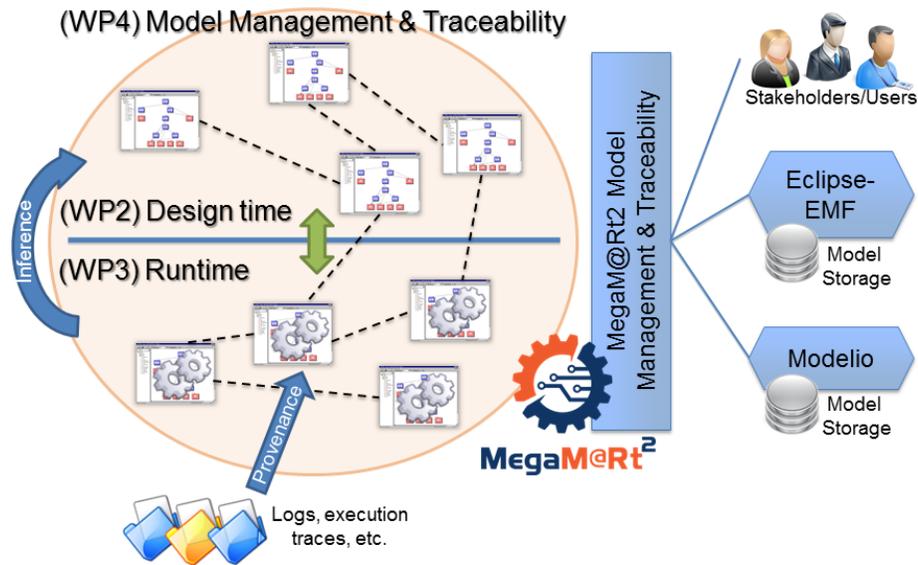


Figure 5: WP4 – Model and Traceability Management approach.

ity solutions [25]. It describes both existing research approaches as well as some more business-oriented tools or environments which are relevant in this given context. Finally, it ends with a list of technical solutions provided by the projects partners. All along the deliverable, a particular importance has been given to aspects related to the scalability of the available solutions.

The main purpose of this deliverable is to prepare the work for specifying the Model and Traceability Management framework to be developed and further used in MegaM@Rt2. Its goal is also to help selecting some of the key problems to be addressed while implementing this framework in the future. Among others, the following big challenges have been identified as important in their respective research areas: scalable model storage and querying, well-synchronized and verified model views, performant and decentralized global model management, efficient integration of inter-model traceability and interoperability support. For further information, interested readers can access the full text of the deliverable

from the project website⁵.

7.5. WP5 - Integration, Case Study Development and Evaluation

This WP provides specific industrial case studies from different domains such as aeronautics, railway, construction and telecommunication. The main goal of WP5 will be to integrate the different technical developments realized in WP2, WP3 and WP4. It will also be in charge of conducting controlled experiments on the case study partner premises, as defined in WP1. Partners in WP5 will perform a preliminary evaluation as feedback for WP2-3-4, and a strong interaction between technology and use case providers is expected. Finally, WP5 will perform the final integration and consolidation of the MegaM@Rt2 solution, as well as the overall validation the obtained results.

7.6. WP6 - Dissemination and Exploitation

This WP concentrates on the project impact and community building activities. These activities will provide a solid base to identify the key stakeholders for sustainable exploitation, dissemination, communication and standardization.

7.6.1. Examples of already produced deliverables in WP6

Public Website and Social Media Presence: A twitter account for the project has been created. Twitter handle is: @megamart2_ecsel. The project website URL is: <https://megamart2-ecsel.eu/>.

Communication Plan: In the initial version of the communication plan, we have identified a preliminary list of stakeholders who would be especially interested in the project and would thus serve as a specific target for our communication and dissemination plan. For further information, interested readers can access the full text of the deliverable from the project website⁶.

⁵<http://hdl.handle.net/20.500.12004/1/P/MMART2/D4.1>

⁶<http://hdl.handle.net/20.500.12004/1/P/MMART2/D6.2>

555 *7.7. WP7 - Management*

This work package gathers all the activities related to the management of the MegaM@Rt2 project and its consortium. This mostly includes the mandatory official monitoring and reporting tasks (to the ECSEL Joint Unit and the European Commission). The overall objective is to ensure a smooth running of the project and efficient collaborations between all the involved partners. As
560 fundamental to the success of the project, this WP will notably coordinate the establishment of a proper quality plan to be applied to all MegaM@Rt2 results. It will also deal with the important risk management and Intellectual Property (IP) issues that may appear during the course of the project.

565 *7.7.1. Example of already produced deliverable in WP7*

Project Management Guide and Quality Plan: The purpose of this deliverable is to present and describe quality standards and procedures to be applied in the internal management and execution of the project. This document is based on the terms and conditions established in the Grant Agreement
570 signed by the ECSEL-JU. This deliverable describes the management roles and functions, the decision and control procedures, the processes and resources for ensuring the quality of project deliverables.

This deliverable is intended to be used by the project management team and the work package leaders, as well as people who are directly responsible for
575 producing the deliverables, to ensure the quality assurance of project processes and outputs and to avoid eventual deviations from the project work plan.

8. Conclusion

This paper presented the MegaM@Rt2 ECSEL project. It notably provided the global context and motivation for this project, introduced its mission and
580 targeted objectives, described its general organization in terms of work packages and detailed the composition of its large supporting consortium. As explained in this paper, MegaM@Rt2 mainly intends to create a scalable model-based framework for dealing with the continuous development and validation of the software

parts of large and complex industrial CPSs. This framework will notably focus
585 on relating together the actual executions of these systems (i.e., runtime) with
the way they are currently specified, developed and maintained (i.e., design
time). While there is already quite a lot of support for these two dimensions
separately, there is currently no real support for an efficient integration and
feedback loop between design time and runtime. We plan to practically realize
590 this by providing the required management and traceability support between all
the involved models (both at design time and runtime). The obtained results
will be experimented on 9 different use cases covering different industrial do-
mains such as aerospace, railway, telecommunication, networks and construction
equipments. In addition to scientific progress in the CPSs and modeling/MDE
595 domains, industrial partners are expected to gain concrete benefits in terms
of improvements to their system reliability and decrease in development and
maintenance costs.

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