



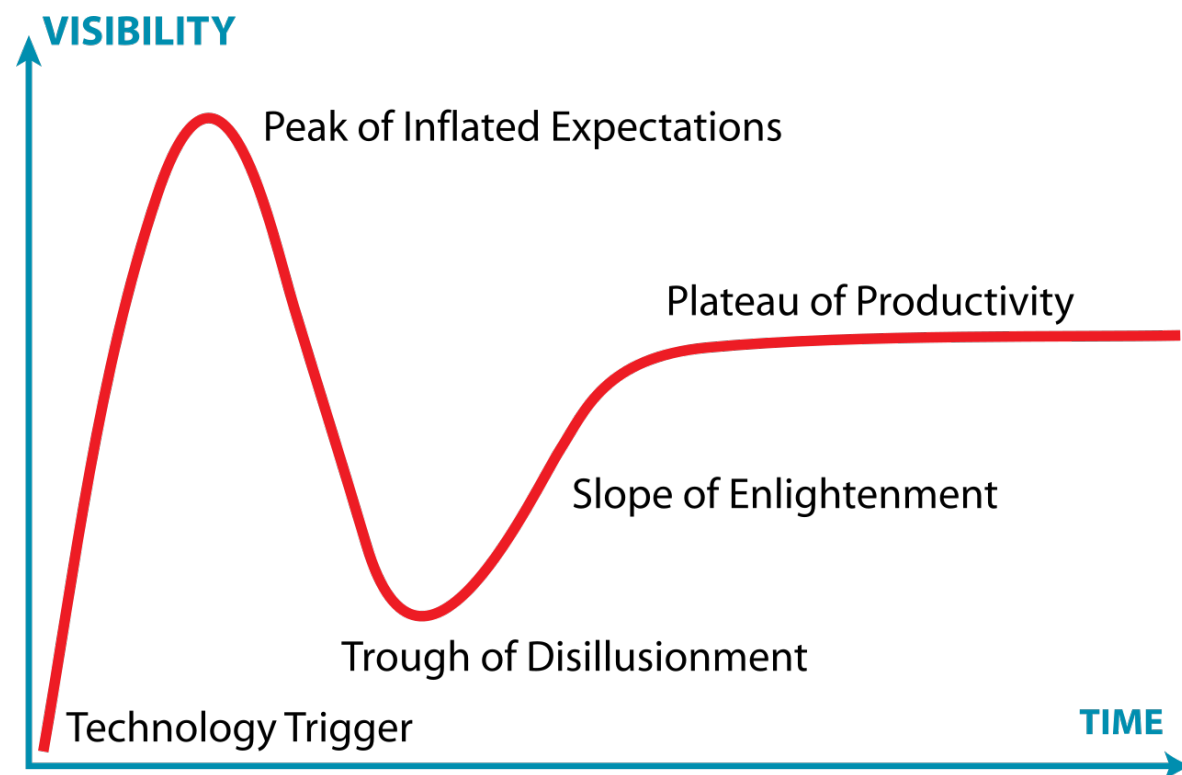
FMI – Status and Outlook

May 28, 2024

Christian Bertsch, FMI Project Leader

History of FMI – hype cycle

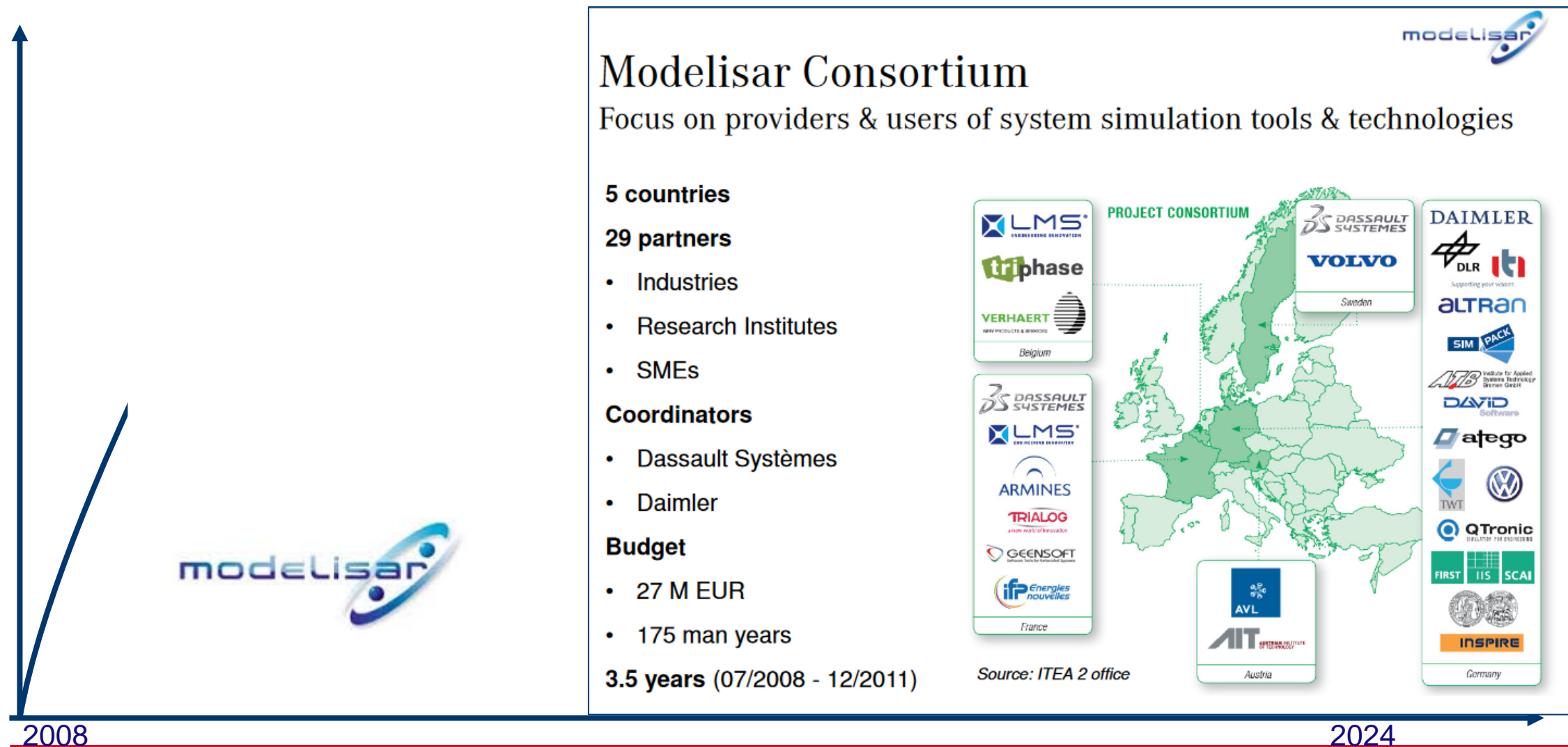
Gartner hype cycle w.r.t. the maturity + adoption of technologies applied to FMI



fmi: Functional
Mock-up
Interface

Source: https://en.wikipedia.org/wiki/Gartner_hype_cycle

FMI hype cycle: MODELISAR



FMI hype cycle: FMI 1.0



FMI 1.0 ME
FMI 1.0 CS

2008

modelisar

The Functional Mockup Interface for Tool independent Exchange of Simulation Models

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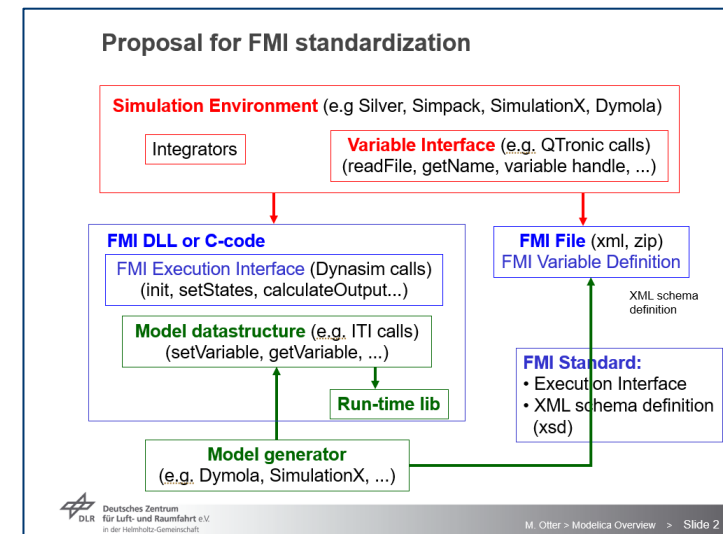
Modelica 2011, 21st, 22nd March

FMI for dynamic system models

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2024

FMI hype cycle: FMI 2.0

FMI 2.0 unifying ME + CS!



FMI 1.0 ME
FMI 1.0 CS

MODELISAR

Functional Mock-up Interface for Model Exchange and Co-Simulation

Document version: 2.0
July 25, 2014

This document defines the Functional Mock-up Interface (FMI), version 2.0. FMI is a tool independent standard to support both model exchange and co-simulation of dynamic models using a combination of xml-files and C-code (either compiled in DLL/shared libraries or in source code). The first version, FMI 1.0, was published in 2010. The FMI development was initiated by Daimler AG with the goal to improve the exchange of simulation models between suppliers and OEMs. As of today, development of the standard continues through the participation of 16 companies and research institutes. FMI 1.0 is supported by over 45 tools and is used by automotive and non-automotive organizations throughout Europe, Asia and North America.

On the Downloads page (<https://www.fmi-standard.org/downloads>), this specification, as well as supporting C-header and xml schema files, and an FMI compliance checker is provided. In addition, sample models (exported from different tools in FMI format) are provided to assist tool vendors to ensure compatibility with other tools, as well as a test suite to check whether connected FMUs are appropriately handled by a tool.

Contact the FMI development group at contact@fmi-standard.org



Functional Mockup Interface 2.0: The Standard for Tool independent Exchange of Simulation Models

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Sweden: ⁶Dassault Systèmes, Lund; ³Modelon, Lund;

France: ¹⁰LMS Imagine, Roanne

Abstract

The Functional Mockup Interface (FMI) is a tool independent standard for the exchange of dynamic models and for Co-Simulation. The first version, FMI 1.0, was published in 2010. Already more than 30 tools support FMI 1.0. In this paper an overview

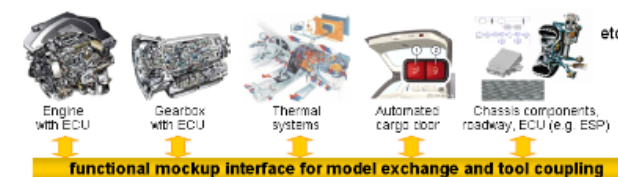
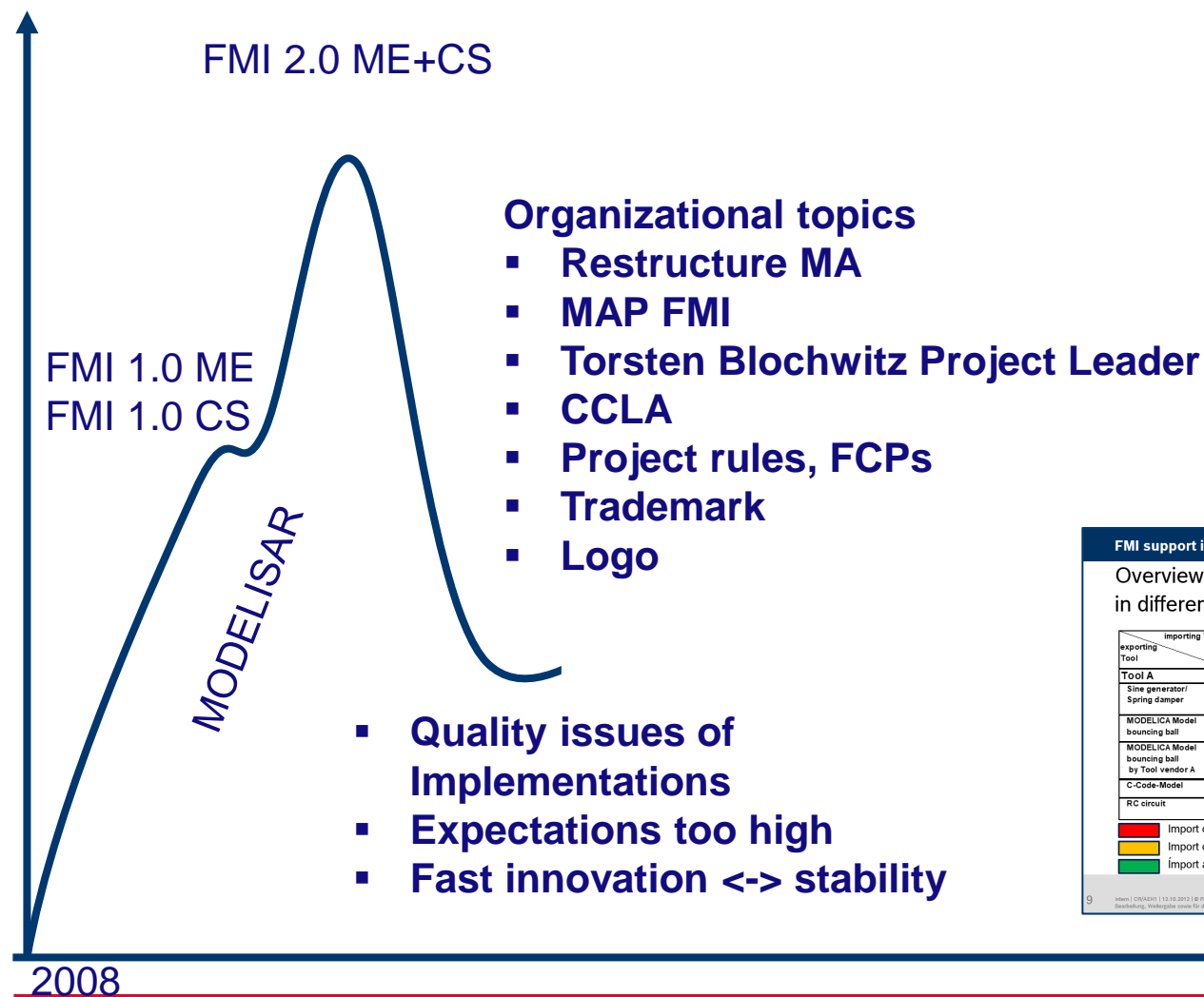


Figure 1: Improving model-based design between OEM and supplier with FMI.

2008

2024

FMI hype cycle



BYLAWS for Modelica Association

Adopted at the statutory annual meeting on February 5, 2000, with changes at the
 _25th meeting on Feb. 7, 2001 in Bielefeld,
 _26th meeting on June 13, 2001 in Linköping,
 _27th meeting on Sept. 7, 2001 in Hartford.
 with further changes at the
 _54th meeting on Nov. 13, 2007 in Paris,
 _55th meeting on Jan. 16, 2008 in Oberpfaffenhofen,
 with further changes at the
 _70th meeting on March 25, 2011 in Dresden,
 _71st meeting on May 23, 2011 in Lund.

FMI support in tools Status 03/2012

Overview: Export of FMUs from **Tool A** and import in different tools

Importing Tool \ exporting Tool	Tool A	Tool B	Tool C	Tool D + Simulink
Tool A				
Sine generator/ Spring damper	no simulation	errors before/ during simulation	No simulation	Simulink crashes
MODELICA Model bouncing ball	different result	Error at simulation	Simulation crashes	Simulink crashes
MODELICA Model bouncing ball by Tool vendor A	works	Assertion failed	Simulation crashes	Simulink crashes
C-Code-Model	Error at import	Error at import	Error at import	Simulink crashes
RC circuit	works	Error Event iteration	Error at import	Simulink crashes

■ Import or simulation not possible
■ Import or simulation with problems
■ Import and simulation works fine

9 © 2012 FMI (Functional Mock-up Interface) Standard. All rights reserved. This document is the property of the FMI Standard. It is not to be distributed outside the FMI Standard. It is not to be used for other purposes without the explicit permission of the FMI Standard. **BOSCH**

FMI is great: But not magic!

- Standardized, open, vendor-neutral API
- Convenient container for handling simulation artefacts: storing, sharing, archiving...
- Free simulation users from modeling/generation tool knowledge
- Reduce IP sharing
- A new quality of simulation is attainable now, because:
 - Producing, sharing and using simulation components is simpler than ever
 - Coupling multi-disciplinary simulations is now more efficient than ever

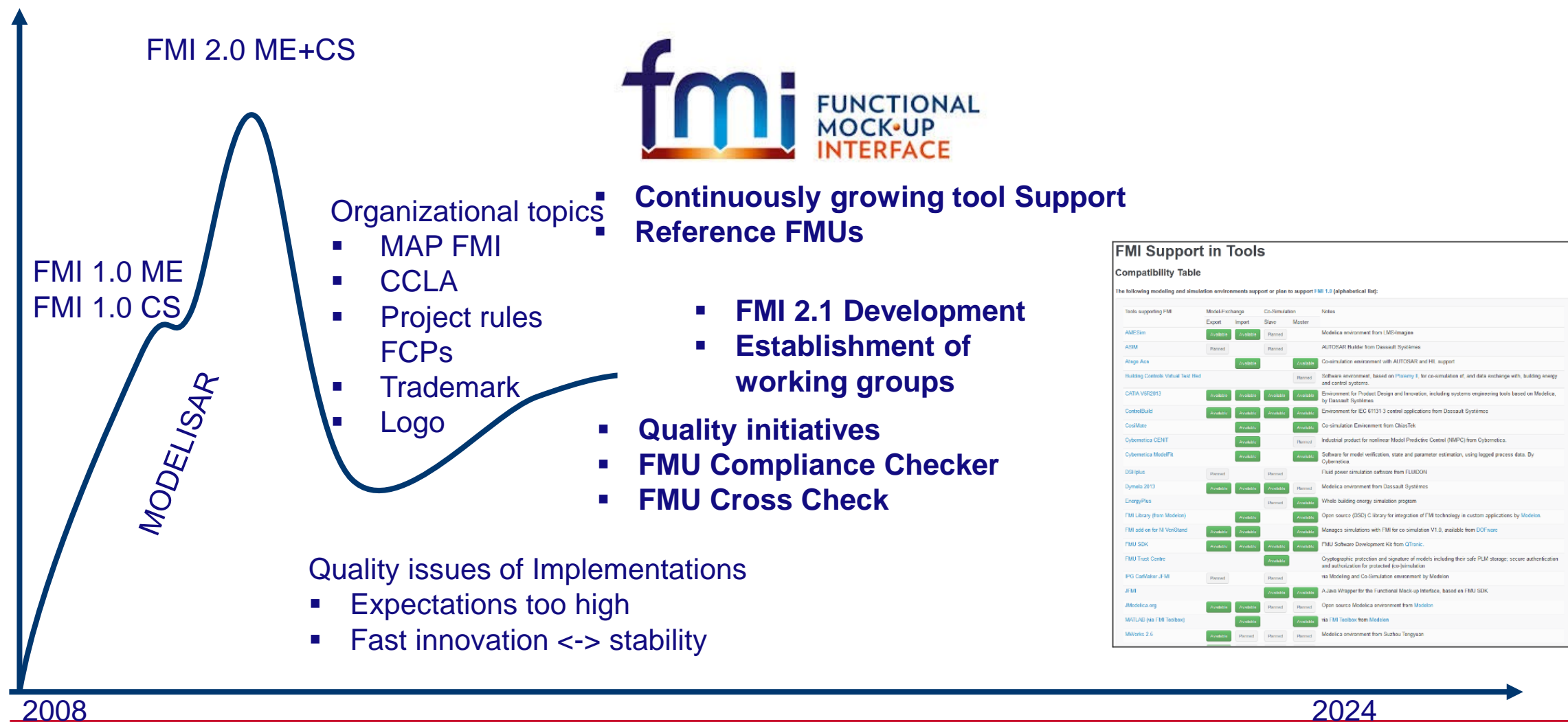
Before FMI

With FMI

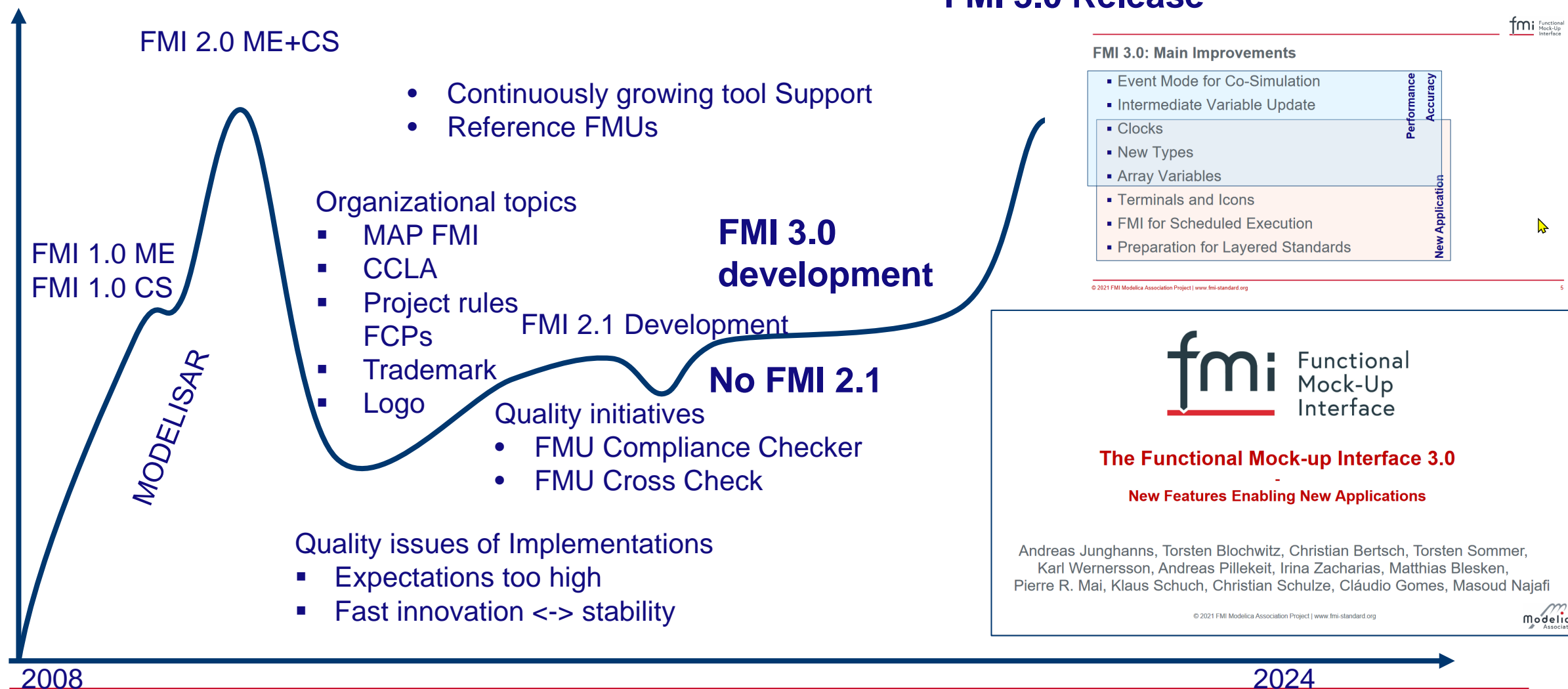
What some of us get

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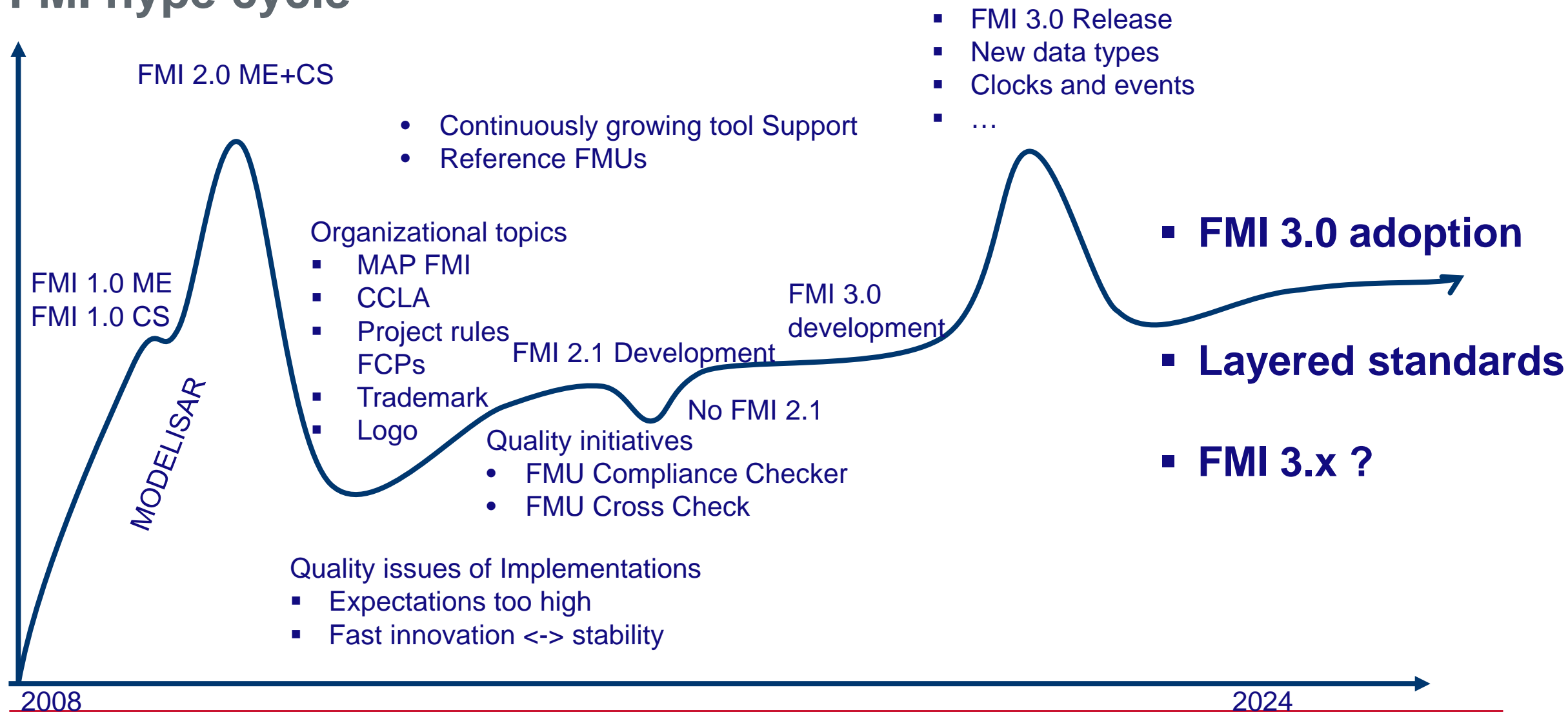
FMI hype cycle: Stabilization and continuation of development



FMI hype cycle: FMI 3.0



FMI hype cycle



Where are we today?

- **De-facto industry standard** for the tool-independent exchange dynamic simulation models
- **200+ tool** listed on FMI tools page:
Typically **good quality** of implementations
 - In industry, **FMI for CS** dominates
 - Usage of **FMI for ME**, e.g., for integration of Modelica support in non-Modelica tools
- **Active design group!**
 - **Members of the Steering Committee:**
AVL List, BOSCH, Dassault Systemes, dSPACE, ESI Group, Maplesoft, Modelon, PMSF, Siemens PLM, Synopsys
 - **Further Contributing Members:**
Aarhus University, ABB, Altair, Akkodis, Ansys, Augsburg University, Danfoss, DLR, EKS INTEC, ETAS, Fraunhofer IEM, ITK Engineering, iVH, JuliaComputing, LTX, Wolfram MathCore AB, TLK Thermo, tracetrionic, TU Dresden
 - **Members of the Advisory Committee (will be strengthened):**
AIRBUS, Beckhoff, COMSOL, Danfoss, Fraunhofer (IIS/EAS First, SCAI), Open Modelica Consortium, Renault, TWT, University of Halle



FMI Design Meeting Munich May 2024

Who uses FMI?: (Employers of the members of the FMI LinkedIn Group, 10/2023)



Aerospace: Airbus, Ascendace Flight Technologies, Boeing, BULATSA, Collins, Dassault Aviation, LIEBHERR Aerospace, Leonardo, Lockheed Martin, NASA, Norasi, Pratt & Whitney,

Automotive OEMs: AMG, Aston Martin, Audi, Bugatti Rimac, Cummins, Ferrari, Ford, GM, Honda, Hyundai, Jaguar Land Rover, Mahindra Racing, MAN, Maserati, Mercedes-Benz, Navistar, Porsche, Scania, Stellantis, Tata, Tesla, Toyota, Uber, Volvo Cars, Volvo, Volta Trucks

Automotive Suppliers: AGCO Power, alvier, Borg Warner, Bosch, CARIAD, Continental, Cyngn, Elektrobit, FPT Industrial, Garrett, Grayson Thermal Systems, Harman, Hyundai MOBIS, Knorr Bremse, Kreisel Electric, Recharge, Schaeffler, SEG Automotive, Traila, Tula Technology, Valeo, Vitesco Technologies, ZF Group

Offroad, Agriculture, Construction, Mining, Railroad: AGROINTELLI, Alstom, Claas, John Deere, Knorr Bremse, KRYTON, LIEBHERR, Putzmeister, Sandvik, Tolsa, Wabtec Corporation

Energy, Heating, CCS: AEP Energy, Bosch Home Comfort, Carrier, BSZ.Netz, Daikin, Danfoss, EDF, e.on Energy Resarch Center, GE-Hitachi Nuclear Energy International, GE Power, Indoorclima, KWS Energy Knowledge, Origen, MAPNA, National Grid ESO, Rolls-Royce Power Systems, Shell, Siemens Energy, SOURCE Global, Sunny Shark, SUNO, Swiss Rotors, Trane Technologies, Vestas, Viessmann, Wärtsilä Energy

Healthcare: Arcabel Solutions, Philips, Quanta Dialysis Technologies, Siemens Healthineers

Automation & Robotics: Balluff, Bucher Emhart Glass., Delta Electronics, Festo, Keba, Rexroth, Rockwell Automation, Stanley Robotics

Mechanical + Electrical + Consumer Products: BSH, ABB, Bosch, Electroingnium, FCK Ingenieria, Groz-Beckert, Heliox, Krones, LG, Mitsubishi, Miele, Samsung, Schindler Aufzüge, SFO, SICK, Siemens, Swegon, Toshiba, Whirlpool

Maritime and Offshore: DNV, IAPS, Naval Group, Rolls-Royce Power Systems, seaplace, Stiesdal Offshore Technologies, TECHNO PRO

Engineering Companies: ALTEN, Akkodis, Arup, ASAP, BeonD, CapGemini Enggineering, DPS, EDAG Group, Edvance, :em, energyflexibility.org, Envinn, EKS InTec , Eradity, FEV, IAV, ITK Engineering, L&T Technology Services, LADUGA, MegaRide, Page Southerland Page, Paninian, Persival, Phimeca, Powersys, Pratt Miller, R&D Test Systems, Sigma Industry, Silver Atena, SVS FEM, Syngineers, Tata Elxsi, Tietoevry, Technica Engineering, Universal Technical Systems, Vestervang Engineering, viatech, Vitech, 8tronix

Tool Vendors: Altair, Ansys, Ape.AI, AVL, BeamNG, CADFEM, Chiatek, Dassault Systèmes, dffrnt.ai, DigSILENT, DMagis, dSPACE, ds.tools, eGolem, ESI, ESSS, ETAS, eXXcellent solutions, Flite Software, Foretellix, Gamma Technologies, Geminus.AI, Global Crown Technology, IVH, JuliaHub, LTX, Maplesoft, MathCore, Modelon, MetaCompliance, MSC Software, National Instruments, OPAL-RT Germany, Optimation, Orthogonal Technology, Semantum Oy, PragmaDev, Siemens Digital Industry Software, Simercator, splight-ai, Synopsys, The MathWorks, TLK Energy, TLK Thermo, TraceTronic, Vector, VIAS3D, VI-Grade, Wolfram, XRG Simulation,

IT+Semiconductors: Akeski IT Solutions, Aras Corporation, Amazon, Apple, Akeski IT Solutions, Aras Corporation, ASML, Atruvia, AWS, Axis Communications, DY Information Technology, Eazy Way Rides, Equinix, Fernride, Infineon, Live Aware Labs, Manzo & Vetere, Microsoft, MoaSoft, Mozilla, Si-Vision, Tata Elxsi, Wedia, WiserBrand, 84codes

Research Institutes: AEE Intec, AIT, CATARC, DLR, Fraunhofer IPK, Indian Institute of Technology, IFP Energies Nouvelles, INRIA, IRT AESE - Saint Exupéry, LBNL, NOBATEK/INEF4, RSE, Ricerca sul Sistema Energetico, SINTEF, Southwest Research Institute, SuperGrid Institute, Swedish National Road and Transport Research Institute (VTI), Virtual Vehicle

Universities: RWTH Aachen, Aalborg University, Aarhus University, Université Amar Telidji de Laghouat, Universiteit van Amsterdam, Augsburg University, Australian National University, Universität Clausthal, University of Colorado Boulder, Comillas Pontifical University, University of La Coruna, DTU, Universiteit Gent, Georgia Tech, TU Hamburg, Universidade Federal de Juiz de Fora , KU Leuven, Lund University, Universidad Politécnica de Madrid, Universidad de Málaga, The University of Manchester, Hochschule München, Ludwig-Maximilians-Universität München, TU München, Università degli Studi di Napoli Federico II , NTNU, University of Oran, University of Pisa, Punjab Engineering College, Instituto Superior de Engenharia do Porto, Charles University Prague, University of Queensland, Rensselaer Polytechnic Institute, Universidad de Sevilla, University of South-Eastern Norway, Stuttgart University, Texas A&M University , University of Trento, TU Wien, Universidad de Zaragoza

Institutions and Associations: European Commission, IDTA, INCOSE,

Other: Carrefour, Citi Private Bank, DeliverMe.City, Fressnapf International Business Services, SIA - Startup Investor Accelerator

Outlook – FMI 3.0 adoption

- **35+ tools with partial FMI support, growing fast**
 - Starting point “basic” CS functionality with basic data types
 - **Step-by-step adoption of new features**
 - Arrays
 - Binary variables
 - CS with events
 - Clocks
 - ...
 - (Scheduled Execution ??)
- **New quality assurance means**
 - Several checkers available
 - Replacement of FMU Cross-check that become unmanageable
 - Tool vendors providing **compatibility information**
 - To come soon: **Challenges and self-certification**

★ Examples & Compatibility



Validate your FMUs

Whether you're exporting FMUs or troubleshooting a third party FMU - the following free tools help you to validate, test and debug your FMUs.



Altair Activate

by Altair

1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0 11.0 12.0 13.0 14.0 15.0 16.0 17.0 18.0 19.0 20.0 21.0 22.0 23.0 24.0 25.0 26.0 27.0 28.0 29.0 30.0 31.0 32.0 33.0 34.0 35.0 36.0 37.0 38.0 39.0 40.0 41.0 42.0 43.0 44.0 45.0 46.0 47.0 48.0 49.0 50.0 51.0 52.0 53.0 54.0 55.0 56.0 57.0 58.0 59.0 60.0 61.0 62.0 63.0 64.0 65.0 66.0 67.0 68.0 69.0 70.0 71.0 72.0 73.0 74.0 75.0 76.0 77.0 78.0 79.0 80.0 81.0 82.0 83.0 84.0 85.0 86.0 87.0 88.0 89.0 90.0 91.0 92.0 93.0 94.0 95.0 96.0 97.0 98.0 99.0 100.0

★ Examples & Compatibility

Software environment for modeling, simulation and analysis of multi-disciplinary systems



MapleSim

by MapleSoft

1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0 11.0 12.0 13.0 14.0 15.0 16.0 17.0 18.0 19.0 20.0 21.0 22.0 23.0 24.0 25.0 26.0 27.0 28.0 29.0 30.0 31.0 32.0 33.0 34.0 35.0 36.0 37.0 38.0 39.0 40.0 41.0 42.0 43.0 44.0 45.0 46.0 47.0 48.0 49.0 50.0 51.0 52.0 53.0 54.0 55.0 56.0 57.0 58.0 59.0 60.0 61.0 62.0 63.0 64.0 65.0 66.0 67.0 68.0 69.0 70.0 71.0 72.0 73.0 74.0 75.0 76.0 77.0 78.0 79.0 80.0 81.0 82.0 83.0 84.0 85.0 86.0 87.0 88.0 89.0 90.0 91.0 92.0 93.0 94.0 95.0 96.0 97.0 98.0 99.0 100.0

★ Examples & Compatibility

Modelica-based modeling and simulation tool from MapleSoft

Outlook – Layered standards to FMI

*Idea: keep **core standard simple** and **extend for special use cases** through standardized means. Current focus of the FMI Design group: work on these layered standards:*

FMI-LS-XCP: XCP support in FMUs

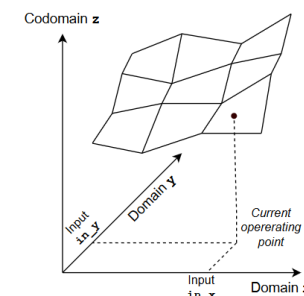
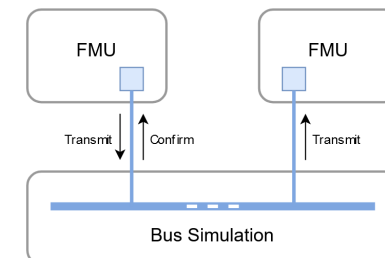
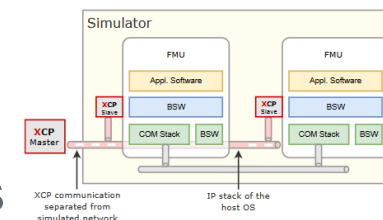
FMI-LS-BUS: network communication with FMI 3.0 means

FMI-LS-STRUCT:

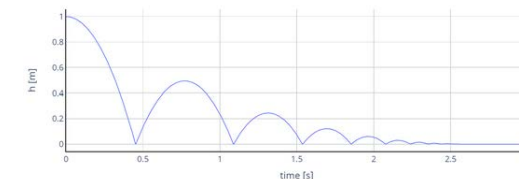
- multi-dimensional lookup tables
- parameter grouping

FMI-LS-REF: references:

- basic experiments with stimuli, reference results:
- related files (e.g. Parameter files in .SSV according to



ssp System Structure & Parameterization



Outlook: Ideas/needs for FMI 3.x from the FMI design group

Most topics of current design group are addressed by FMI 3.0 or can be handled by layered standards

Current investigation:

Efficiency improvements in the get/set functions possible?

- Approach for **direct memory** access proposed
- “**eFMI**”-like approach for source code FMUs
- *Hard to evaluate need and benefit on modern computer platforms*
- *Sparse array access?*
- *Optimized access to partial derivatives for optimization use cases?*



Outlook: Further ideas/needs for FMI 3.x?

Question: are there needs for improvement from other fields, e.g. for FMI for ME?

DAE support FMUs??

- Conceptual work in FMI Working group 2012-2018
- Open questions e.g. w.r.t. to initialization prevented inclusion in FMI 3.0
- *Currently no driver from industry nor tool vendors, academia*

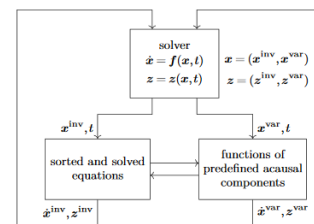
Former Proposals

History of (some) DAE Proposals:

- **2015 Velizy**: Semi-implicit DAEs of arbitrary index; all „hidden“ constraints (index reduced constraints) are also defined
→ decision to stick to index 1
- **2016 Renningen**: Semi-implicit DAEs of index 1; dependencies for constraints available (Jacobian's of constraints available)
- **2017 Paderborn**: just refinement of the 2016 status; proposal for implicit DAEs
→ need for higher index (at least implicit index 2)
- **2018**: Proposal for index 1 DAEs with projection handling for higher index
- **2018 Dresden**: merged proposal

Acausal FMUs??

- Previous work by DLR*
- Work package in ITEA Project OpenSCALING



*Neumayr, Andrea and Martin Otter (2023b).
*Variable Structure System Simulation via
Predefined Acausal Components*. Modelica'2023 Conference.

If you want to follow up with these or other ideas, please get active in the FMI project!

Form working groups to create FMI Change Proposals (FCP), including use case description, fit to the FMI standard and its design principles, technical realization, prototype implementations ...)

Thanks Martin, for your great contributions to the FMI standard!

*How to access and (co)-simulate models
in a standardized way?*



Prof. Dr.-Ing. Martin Otter



fmi Functional
Mock-up
Interface **!**

