Framework for Integration of Virtual Metrology and Predictive Maintenance

15. Workshop der GMM – Fachgruppe 1.2.3 Abscheide- und Ätzverfahren

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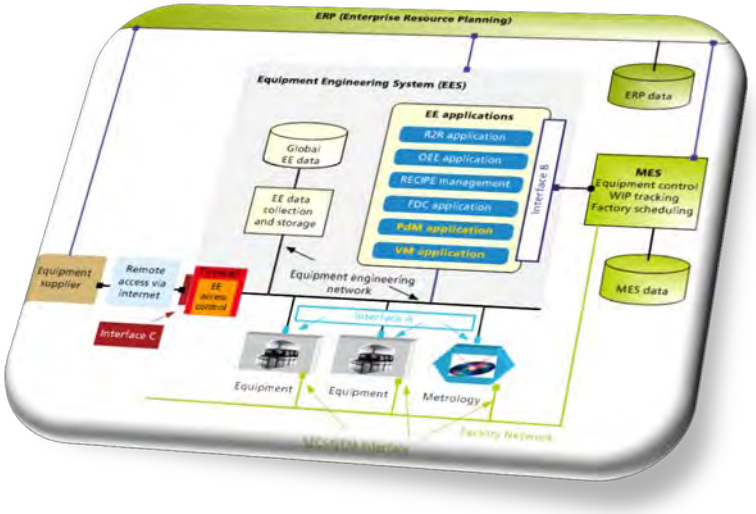

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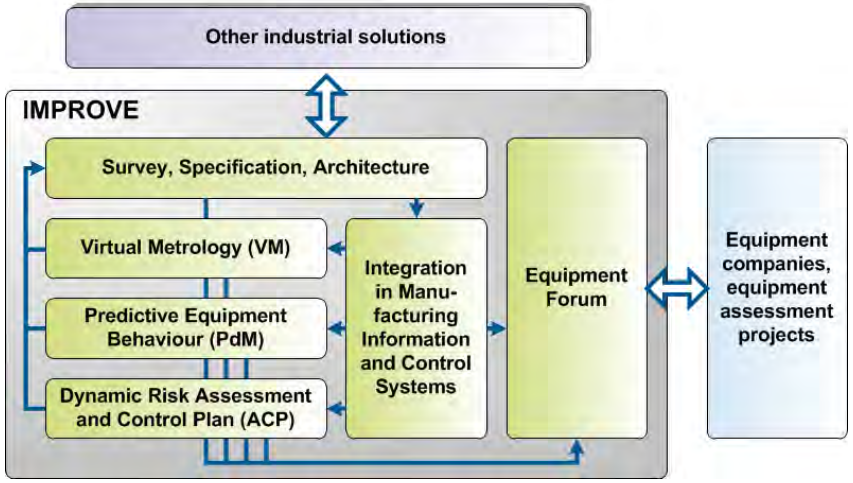
Outline

- The IMPROVE Project at a Glance
- Motivation
- Virtual metrology (VM) and predictive maintenance (PdM)
- Approach for a generic and reusable framework architecture
- Modeling and implementation of the framework
- Implementation and test of the framework in fab environments
- Conclusion

Framework for Integration of Virtual Metrology and Predictive Maintenance - The IMPROVE Project at a Glance (1/3)

Implementing Manufacturing science solutions
to increase equiPment pROductiVity and fab pErformance

- Main objective: IMPROVE European Fab's Competitiveness, by
  - improving processes reproducibility and quality
  - improving the effectiveness of production equipment
  - shortening cycles time and improve learning curve
- Three Manufacturing Science R&D Topics
  - Virtual Metrology
  - Predictive Maintenance
  - Dynamic Control Plan
- Two Support Activities
  - Survey, Specifications and Architectures
  - Equipment Forum



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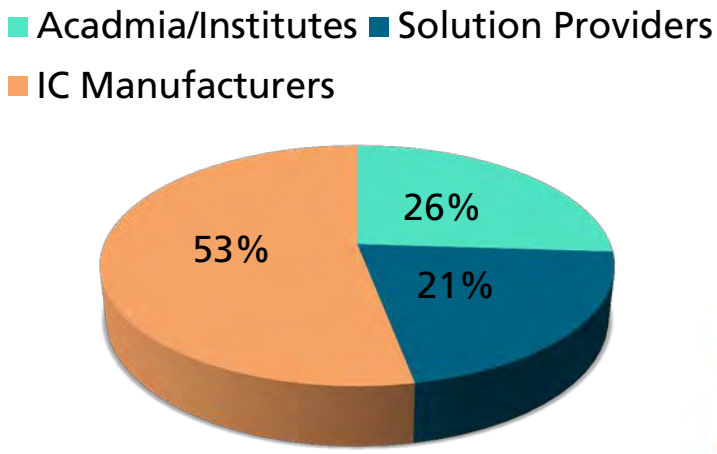
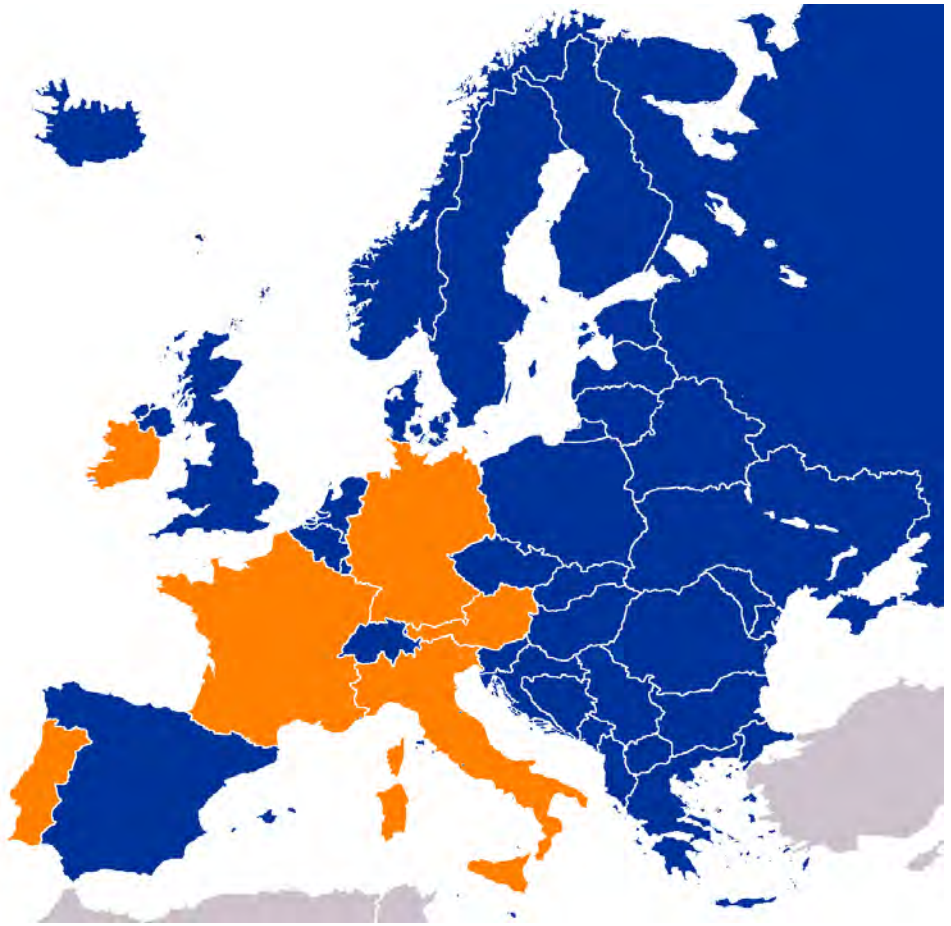
Framework for Integration of Virtual Metrology and Predictive Maintenance - The IMPROVE Project at a Glance (2/3)

Key figures

- 3600 men-months over 3 years
- 100 full-time researchers
- January 2009 to July 2012
- 35 partners over 6 countries





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Framework for Integration of Virtual Metrology and Predictive Maintenance - The IMPROVE Project at a Glance (3/3)

The IMPROVE Partners

- 6 major European IC manufacturers
- 2 Institutes
- 12 Academic labs
- 10 Solution providers

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Framework for Integration of Virtual Metrology and Predictive Maintenance - Motivation

- Complex systems for process control in semiconductor manufacturing
  - SPC, fault detection and classification, run-to-run control, and others
- Various approaches for the actual implementation possible
  - Some fabs implement new control entities equipment by equipment
  - Others follow dedicated bottom-up or top-down approaches
- Challenge: Implementation of new control paradigms in existing fab systems with different IT infrastructure?
- European project "IMPROVE"
  - Development of novel methods and algorithms for virtual metrology (VM) and predictive maintenance (PdM)
  - Challenge: How to ensure the reusability of developed solutions amongst the nine IC manufacturers' fabs gathered in IMPROVE?

➔ Need for a **common architecture** and **optimized algorithms** to integrate VM and PdM into the different existing fab systems

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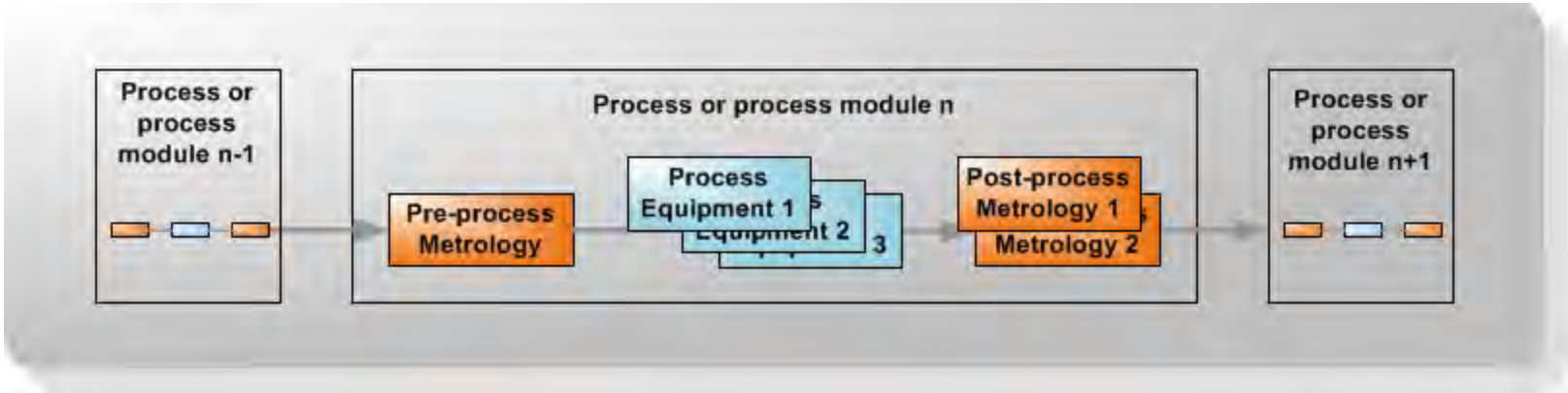
Virtual metrology (VM) and predictive maintenance (PdM)
Concept of VM for IC-manufacturing

- State-of-the-art
  - In current IC manufacturing, achievement of process stability and high production yield relies on reliable wafer monitoring by physical metrology
  - Critical parameters are assessed using monitor or product wafers
  - No broad implementation of concepts like virtual metrology
- Deficiencies for monitoring and process control
  - Limited possibility for process monitoring and control on wafer-to-wafer or on real-time basis
  - Critical parameters may not be measurable with in-line measurements



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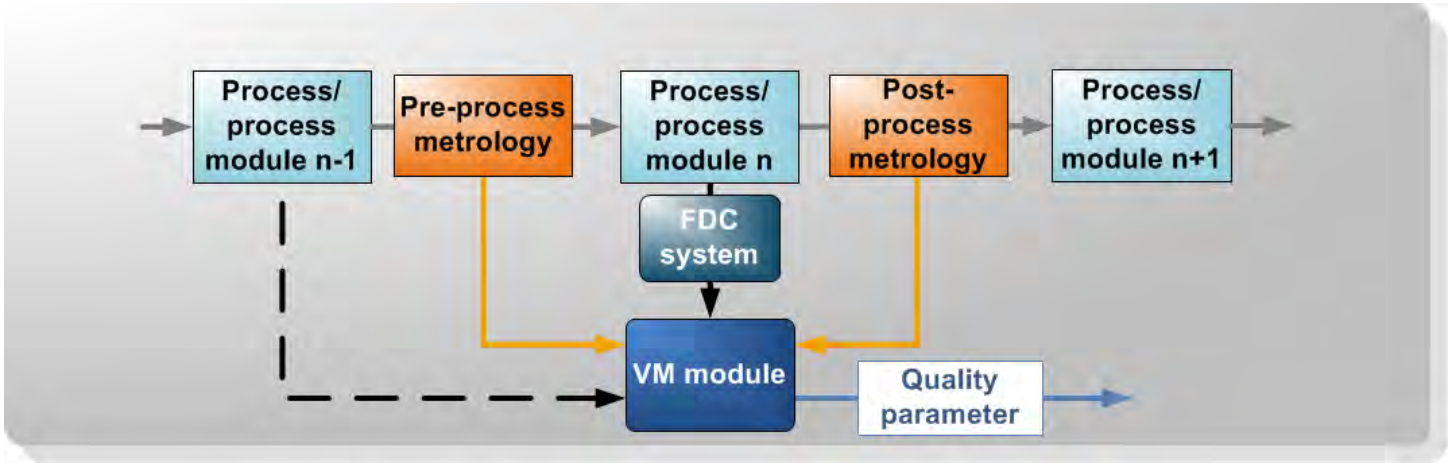
Virtual metrology (VM) and predictive maintenance (PdM)
VM objectives and benefits

- VM definition
  - Technology of prediction of post process metrology variables (either measurable or non-measurable) using process and wafer state information that could include upstream metrology and/or sensor data.
- VM benefits
  - Improved understanding of unit processes
  - Support or replacement of stand-alone and in-line metrology operations
  - Support of FDC, run-to-run control, and PdM
  - Improved equipment control for VM running on equipment level



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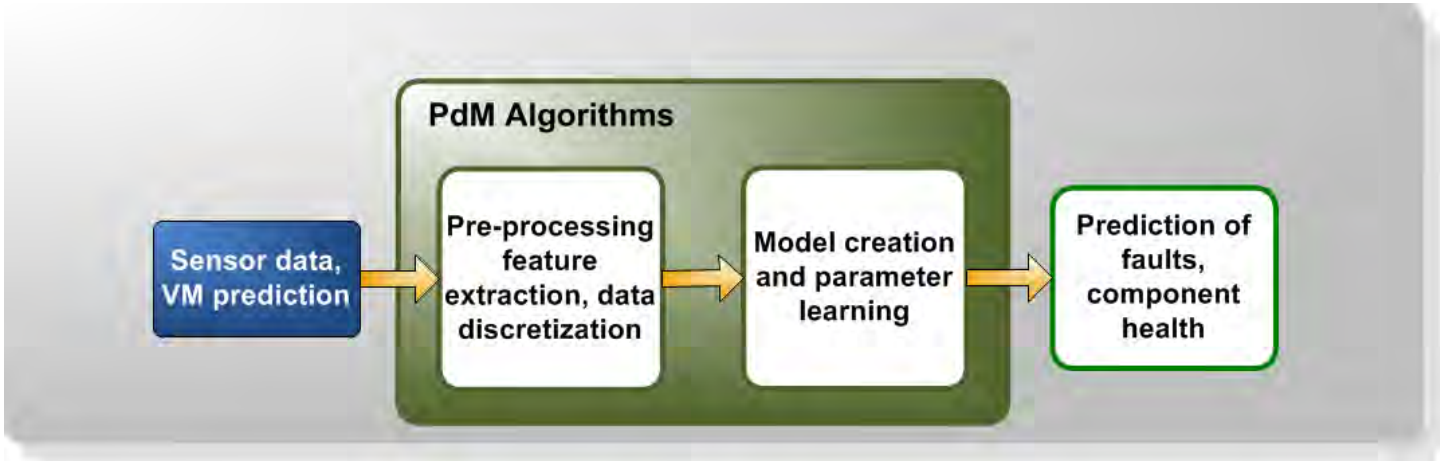
Virtual metrology (VM) and predictive maintenance (PdM)
Concept of PdM for IC-manufacturing

- Current situation of scheduled maintenance in semiconductor manufacturing
  - Maintenance schedule based on elapsed time or fixed unit count usage
  - Maintenance frequency mainly depends on the process engineer's experience and on known wear out cycles of certain parts of the tool
  - The considerations for preventive maintenance are generally based on worst case scenarios to avoid unscheduled maintenance due to unforeseen failures
- Ideal maintenance strategy - "Run to almost fail"
  - Predictive maintenance aims at replacing/repairing an equipment part when it has nearly reached its end of life



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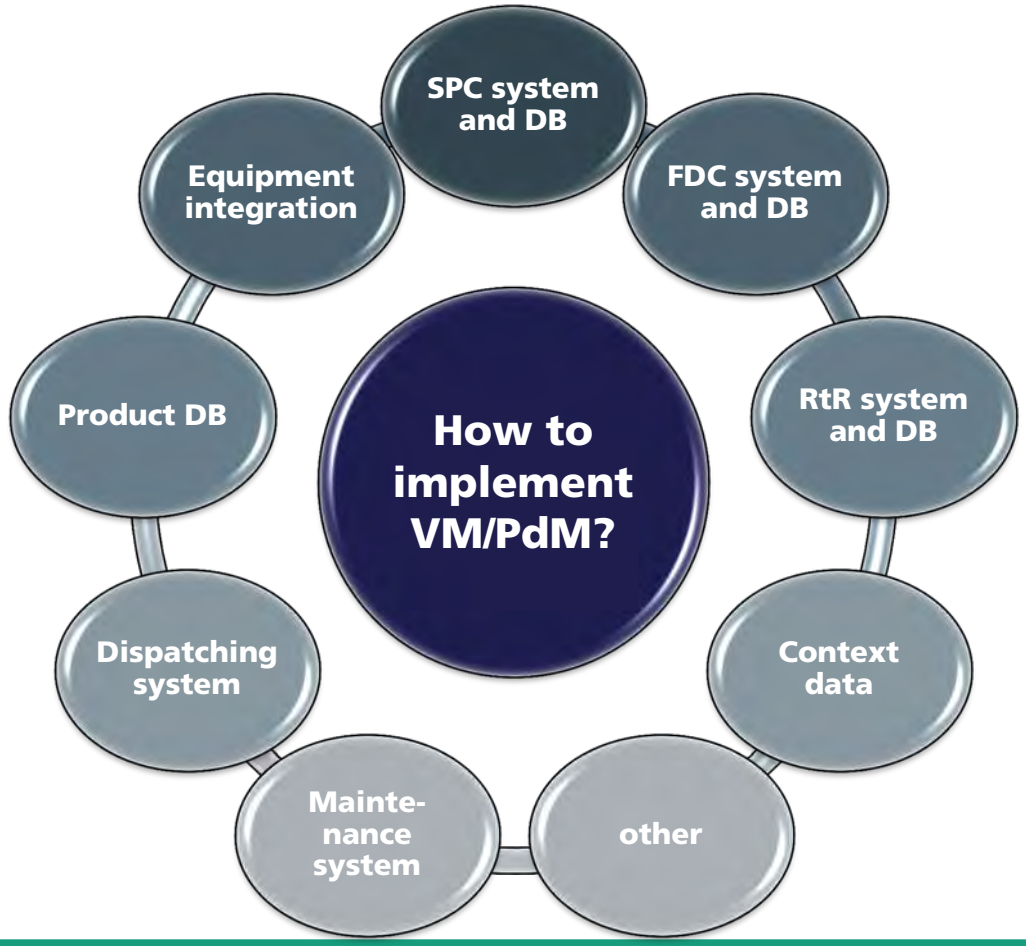
Approach for a generic and reusable framework architecture
Initial situation

Typical available databases and fab applications



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Approach for a generic and reusable framework architecture
Architecture expectations and prerequisites

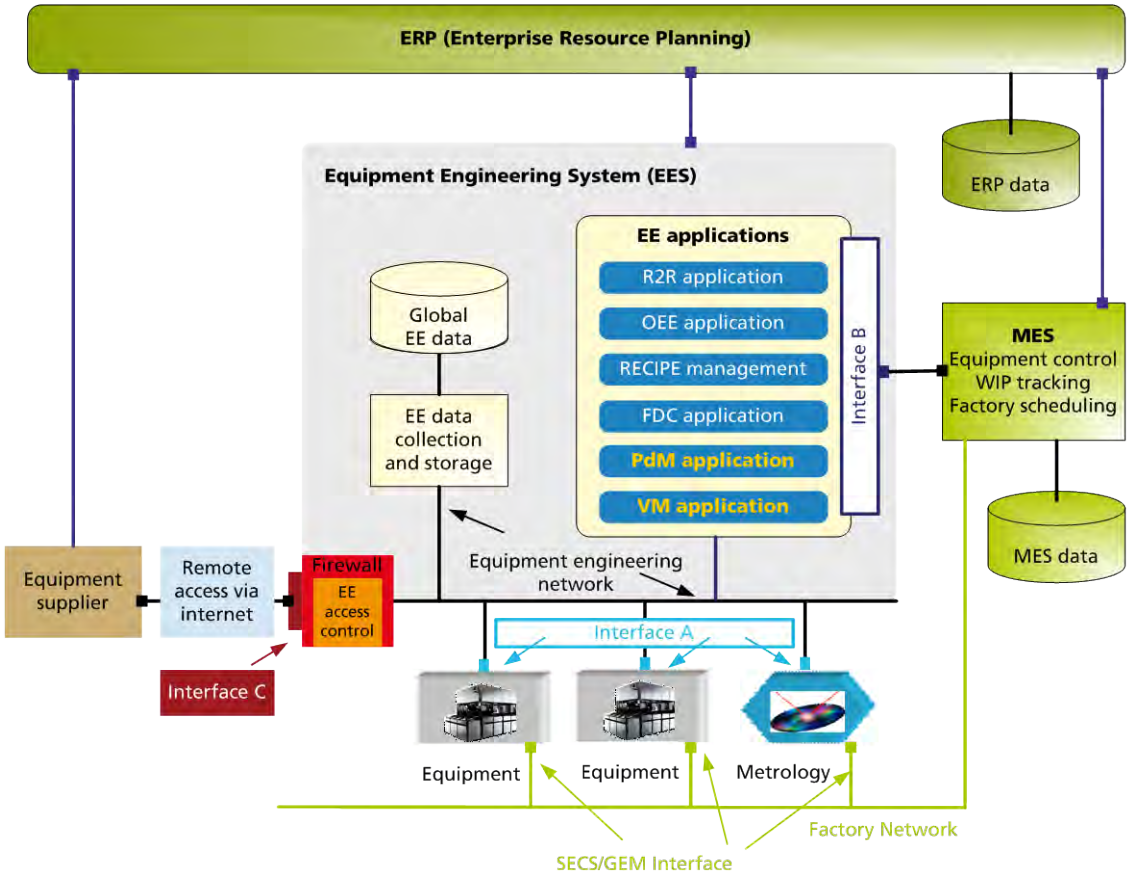
- Development of a VM/PdM architecture
  - Abstract from IT infrastructure of IC-manufacturers using an ideal architecture
  - Integration of VM and PdM modules into a common model
  - Mapping the ideal architecture to the existing infrastructures applying UML and developed software solutions

- Avoidance of island solutions by
  - Generic specifications and high reusability
  - Improved efficiency of design and implementation phases
  - Thorough analysis instead of ad hoc solutions and workarounds

Approach for a generic and reusable framework architecture

Concept for generic VM/PdM implementation

Definition of VM and PdM as EE applications on a conceptual level



- Abstraction from existing fab infrastructures
- Application of existing SEMI standards possible, including especially interface A and interface B standards
- Extension of the existing SEMI standard E133 to include VM

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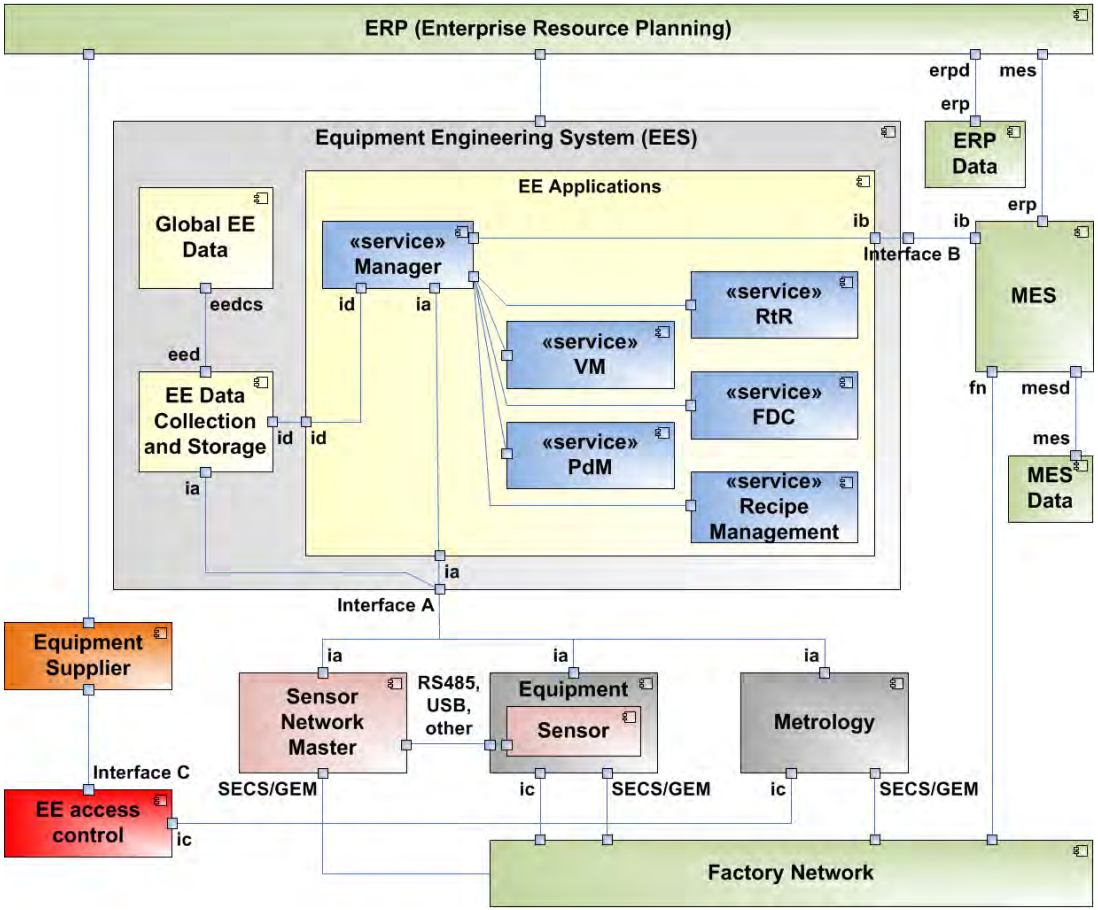
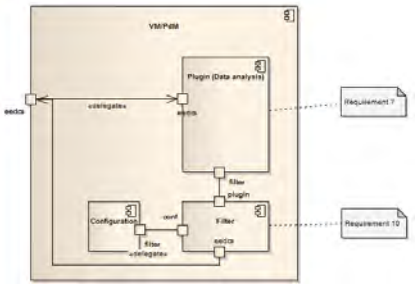
Approach for a generic and reusable framework architecture

Concept for generic VM/PdM implementation

UML description of the EE system and of a generic VM/PdM module





- Mapping to existing infrastructures
- Consideration of specific user requirements
- VM/PdM module: Inclusion of configuration, data analysis, and filter modules as plug-ins

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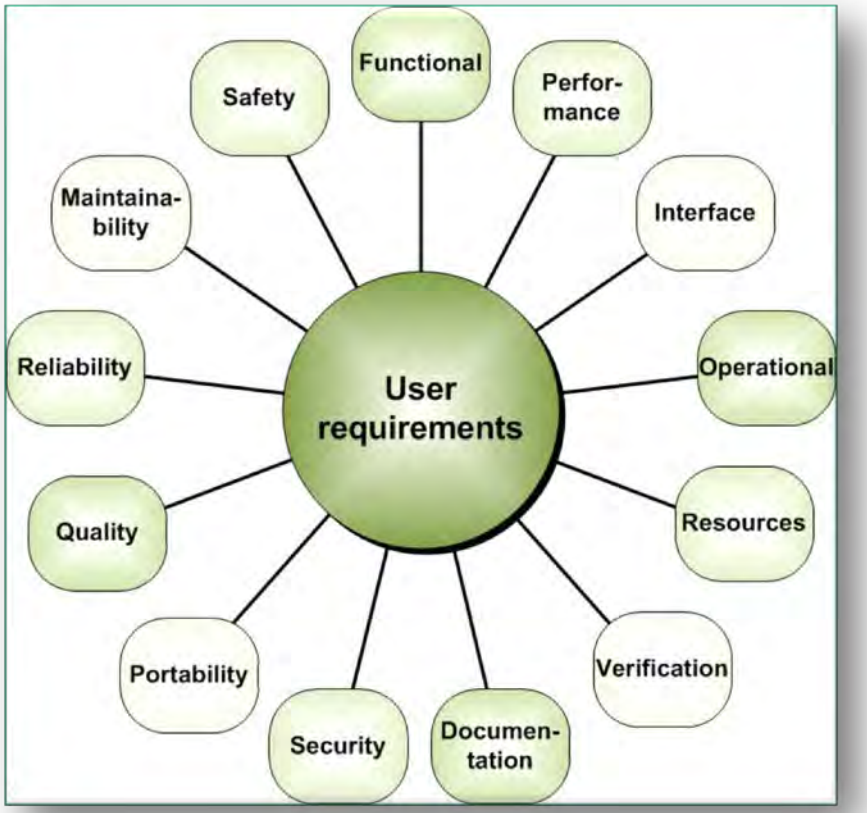
Approach for a generic and reusable framework architecture
Consolidation of user requirements

Approach

- Catalogue with quantifiable criteria and well defined classification of user requirements for VM, PdM, and the framework architecture
- Collection of feed-back from all users involved in IMPROVE
- Consolidation of user requirements

Classification of specific user requirements



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Modeling and implementation of the framework

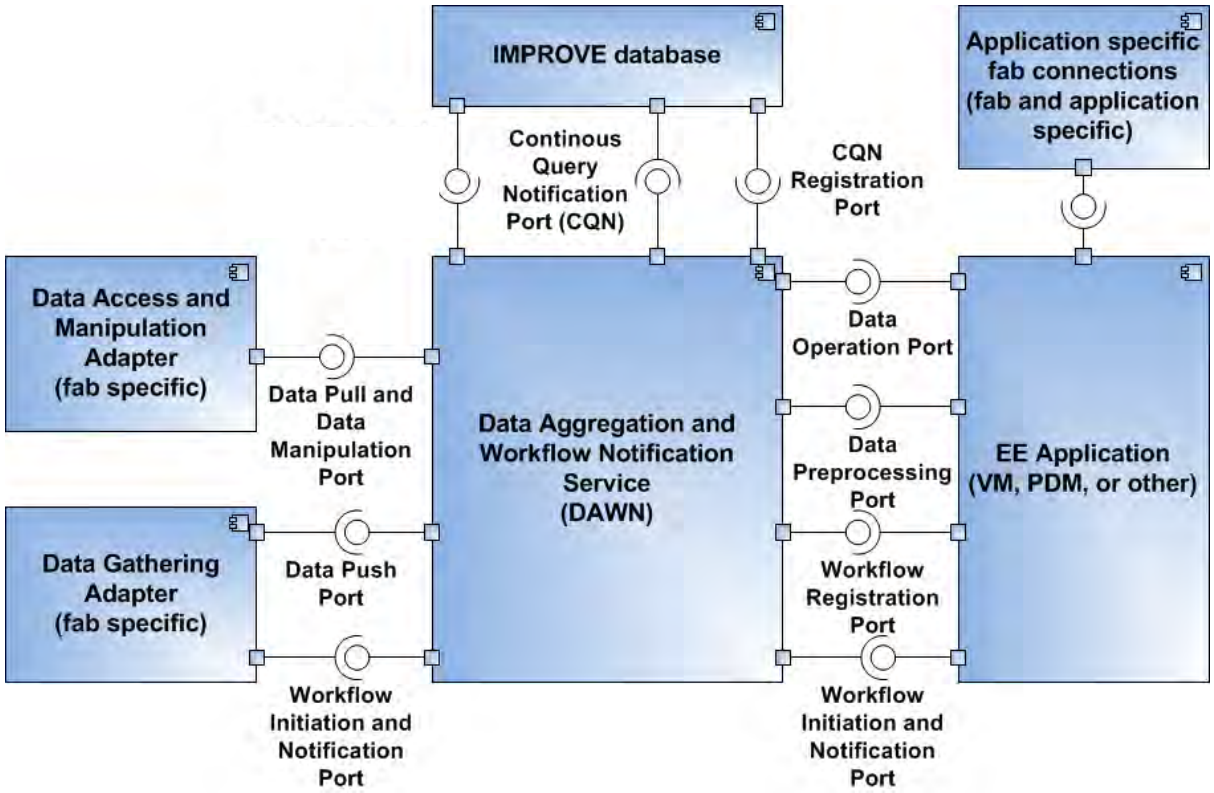
User requirements - examples

Type	Requirement
Functional	URF001: VM prediction result • The SW shall predict the result of a metrology measurement. • The SW shall predict measurements based on algorithms (site, wafer or lot fine).
Interface	URI001: VM data sources • The predicted result is calculated by algorithms, e.g. by multivariate analysis from input data from the following possible data sources: SPC-Data, FDC-Data, RtR-Data, Sensor-Data others
Maintainability	URM001: VM tool plug-ins and libraries • The multivariate analysis algorithms are not hardcoded, but parameterized plug-ins with defined interfaces. The algorithms are in form of a library easily changeable. • If there is a new algorithm plug and play and in form of library MATLAB, R, C++,… is required.

Modeling and implementation of the framework

Modeling of the IMPROVE framework

Main components and connections of the IMPROVE framework



IMPROVE framework: Transparency layer between the different fab architectures and the EE application modules

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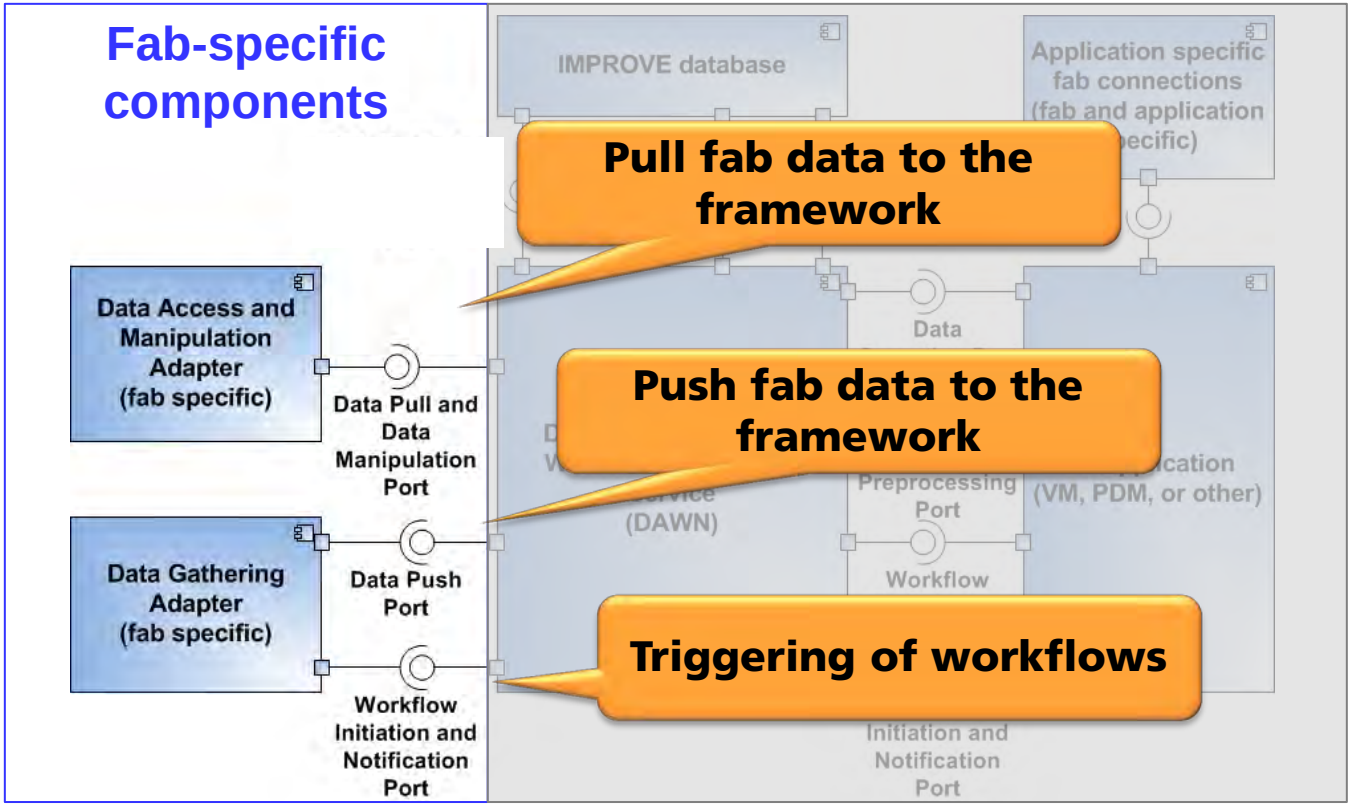
Modeling and implementation of the framework
Modeling of the IMPROVE framework

Main components and connections of the IMPROVE framework



IMPROVE framework: Transparency layer between the different fab architectures and the EE application modules

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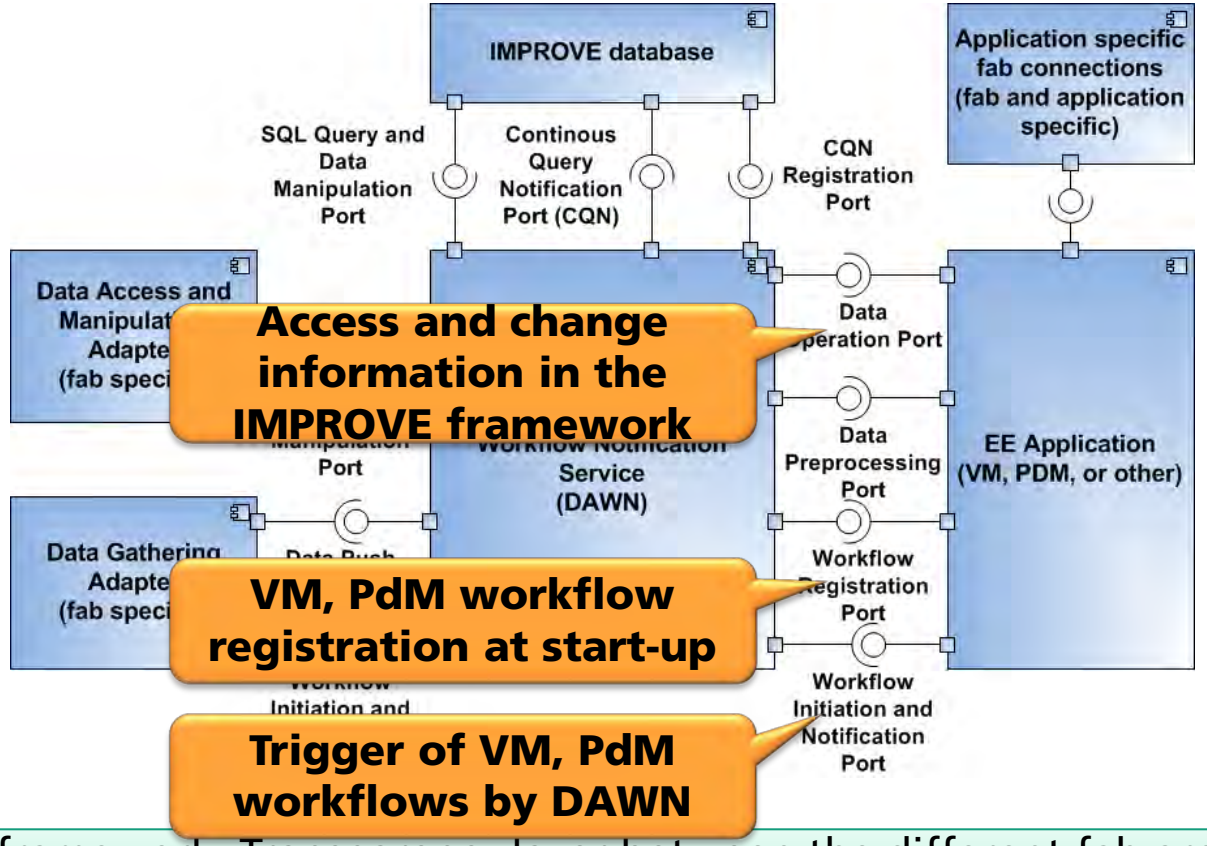

IMPROVE framework: Transparency layer between the different fab architectures and the EE application modules

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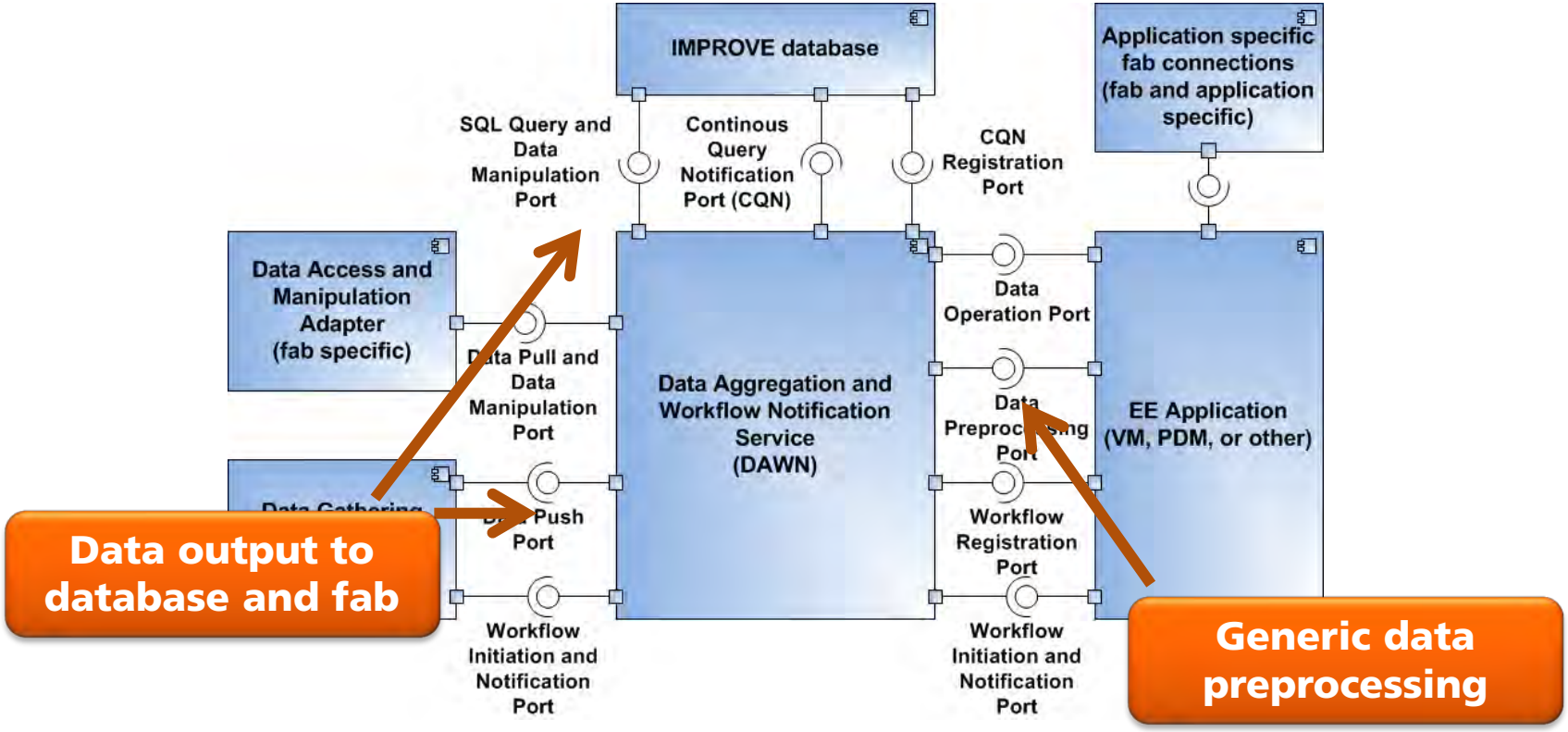

IMPROVE framework: Transparency layer between the different fab architectures and the EE application modules

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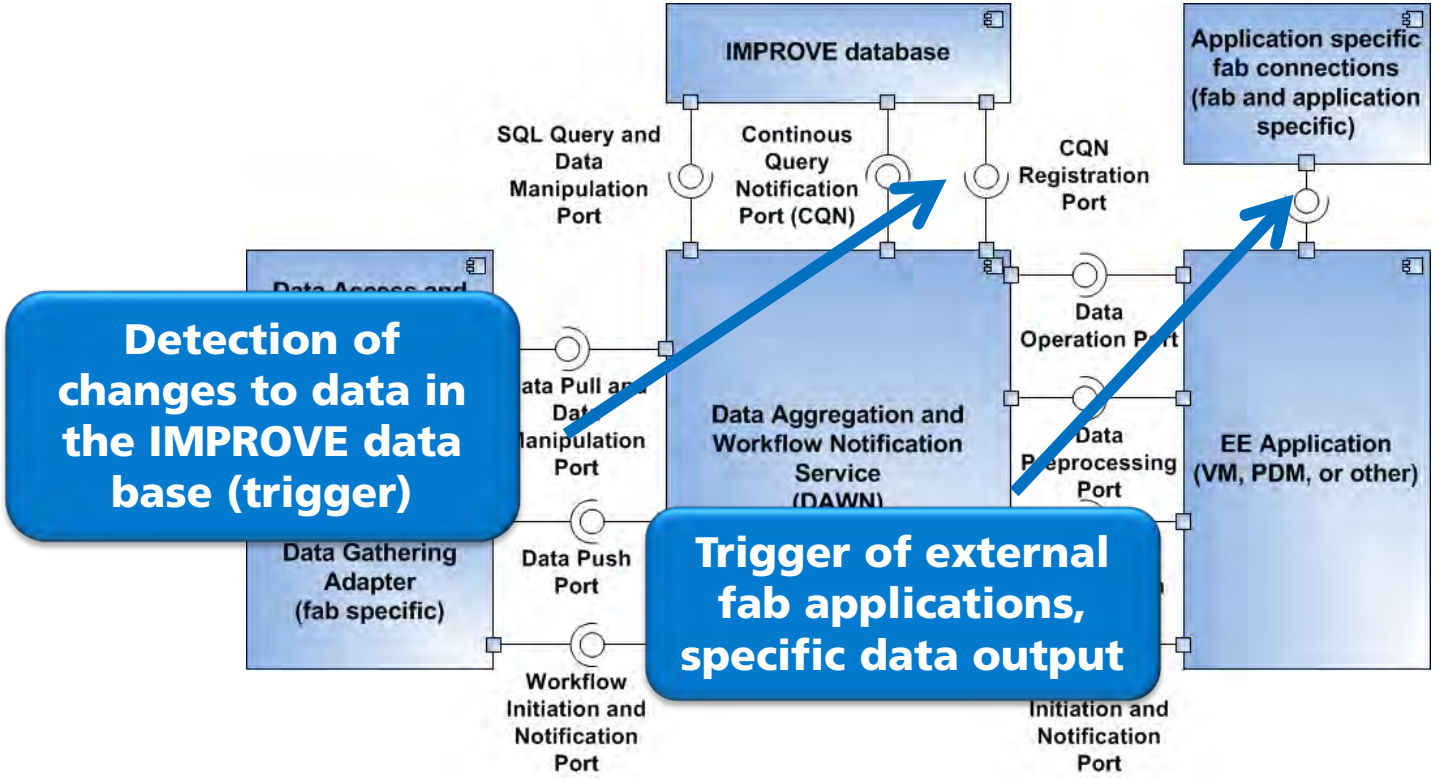

IMPROVE framework: Transparency layer between the different fab architectures and the EE application modules

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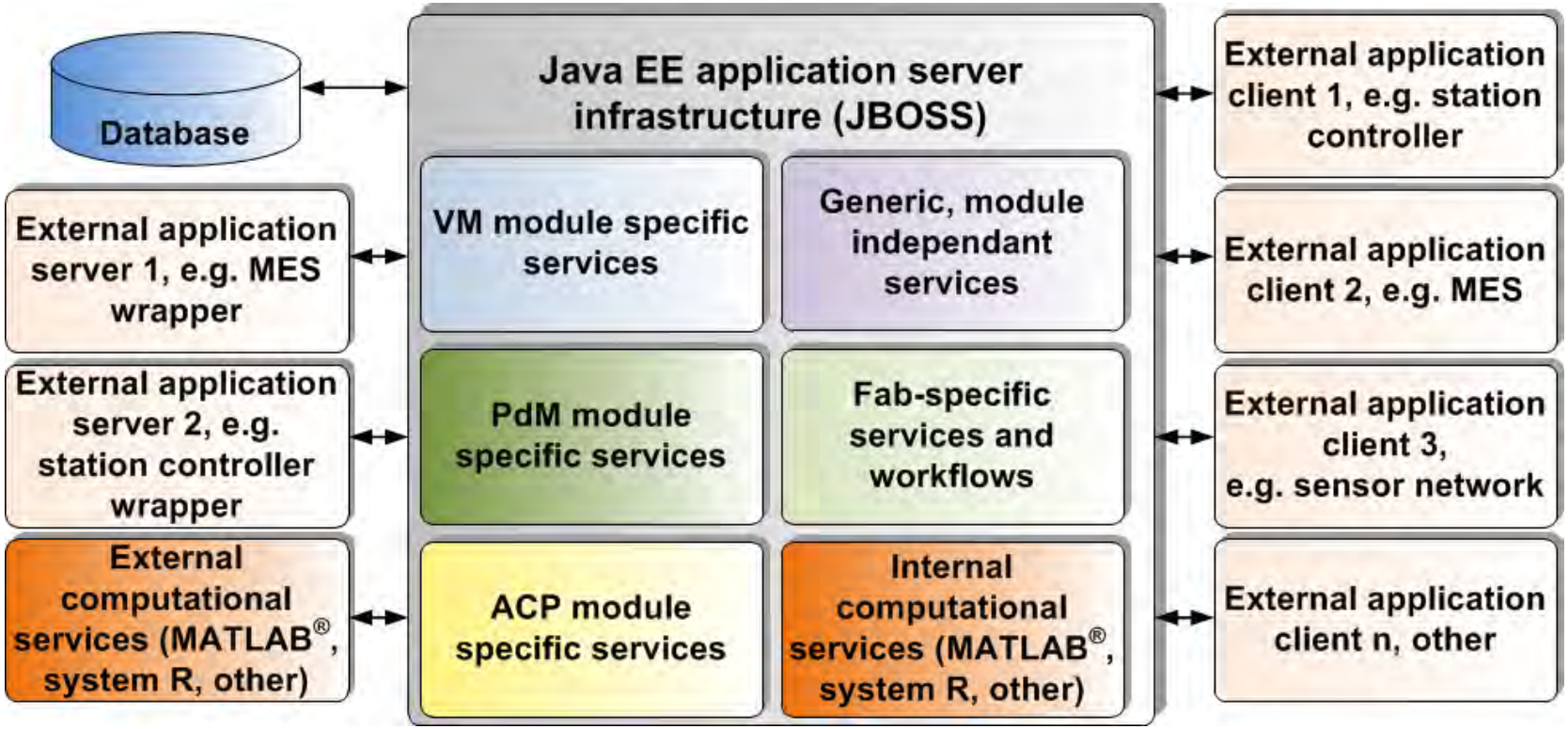
Approach for a generic and reusable framework architecture
Software implementation of the framework (1)

- Main features
  - Compliance with state-of-the-art technologies (Java Enterprise Edition platform, Enterprise Java Beans -EJB)
  - Use of WEB-services (SOAP, WSDL) at the communication layer
    - integration of modules from different platforms and operating systems and
    - simple integration of equipment connectors (station controllers) and legacy applications
- Workflow tool
  - visual creation and change of process flows
  - changes of workflows possible at runtime and parallel execution for new-version testing
  - any module inside the IMPROVE framework can be used inside a workflow
- Main components of the framework
  - JBOSS 7 Application Server, JBPM 5 Workflow Engine,
    Oracle Database 11, Listeners, Clients, Software modules realized as EJBs

Approach for a generic and reusable framework architecture
Software implementation of the framework (2)

Software implementation of the framework and available services



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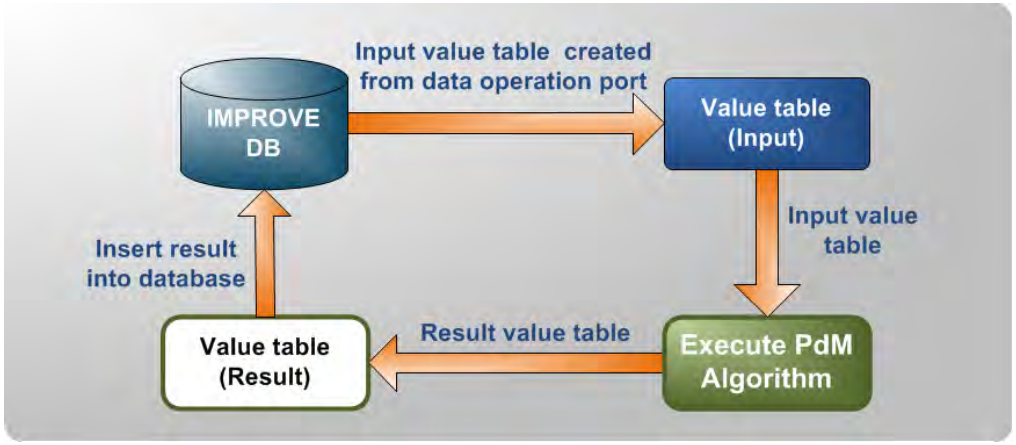
Implementation and test of the framework in fab environments
Implementation and test at Infineon Technologies

- Registration of a PdM algorithm at DAWN and database (data operation port, CQN registration port)
- Push of new data from the internal FDC database into the DAWN component and IMPROVE database (fab specific data gathering adapter, data push port, SQL query and data manipulation port)
- Trigger of PdM algorithm (continuous query notification port, data operation port)
- Conversion of value table into a MATLAB matrix and execution of MATLAB-based PdM algorithm
- Conversion of result from a MATLAB matrix into a value table; return and storage of result in IMPROVE database (data operation port, SQL query and data manipulation port)
- Result is available to trigger further actions (e-mail notifications, SAP maintenance requests, production equipment stops)



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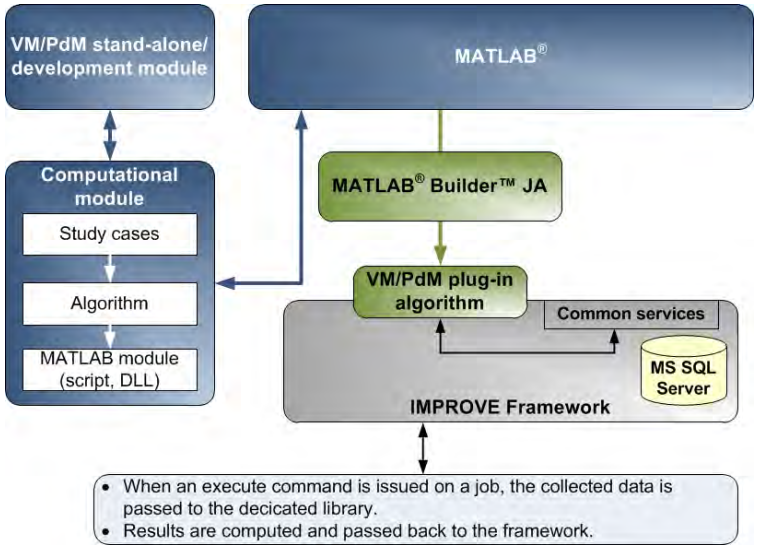
Implementation and test of the framework in fab environments
Implementation and test at Micron (Agrate)

- Test on PdM (required electrostatic chuck change) and VM (prediction of CD in a dry etch process)
- Selection of a Microsoft (MS) SQL Server as database platform
- Development of a specific data loader to merge data from two different FDC systems and two metrology measurements
- Extension to have a separate "development platform" for coding, maintenance, algorithm update and test, validation of code, and deployment
  - Compilation of the VM/PdM modules to Java
  - Testing of the Java package
  - Integration of the tested VM/PdM modules into the framework



Application	Algo-rithm	Response time			
		Target	MATLAB	Java	Frame-work
PdM	Gamma Filter	minutes	< 7 sec	< 10 sec	< 39 sec
VM	Lasso	(periodically)	< 1 sec	< 2 sec	< 1 sec
VM	Predic-tion	minutes	< 1 sec	< 2 sec	< 1 sec

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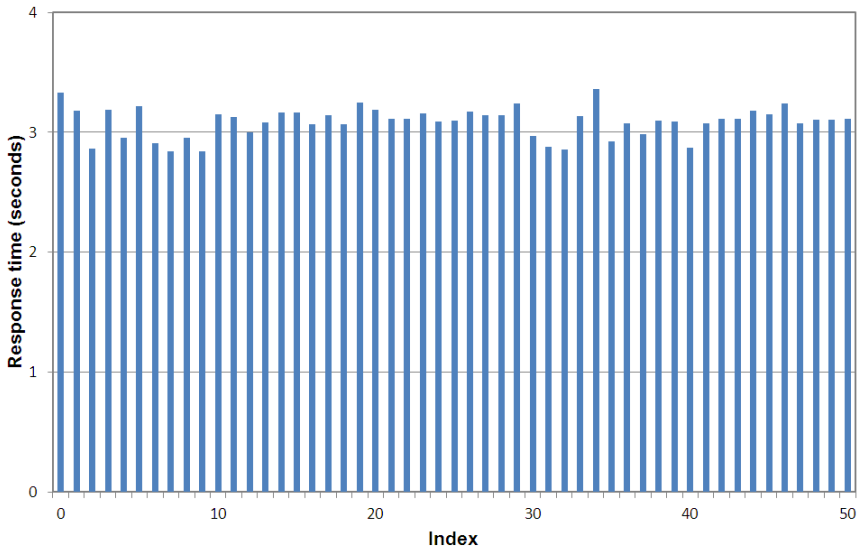
Implementation and test of the framework in fab environments
Implementation and test at ams AG

- Test on a PdM use case to trigger a maintenance action and replace the source of a medium current implanter
- PdM algorithm for calculation of the projected remaining lifetime available as a plug-in programmed within the open source statistics package R
- Applying the specific data adapters, real time FDC data from the implanter is pushed into the framework and to the PdM module
- Passing of result to the framework and SPC system for visualization and to trigger an e-mail alarm 48 hours ahead of the projected breakdown
- Successful test of configuration in 24/7 production environment over two months
- Overall response time of 25 s satisfactory for PdM applications (delay time mainly by the provisional fab adaptors used, 3 s caused by framework)



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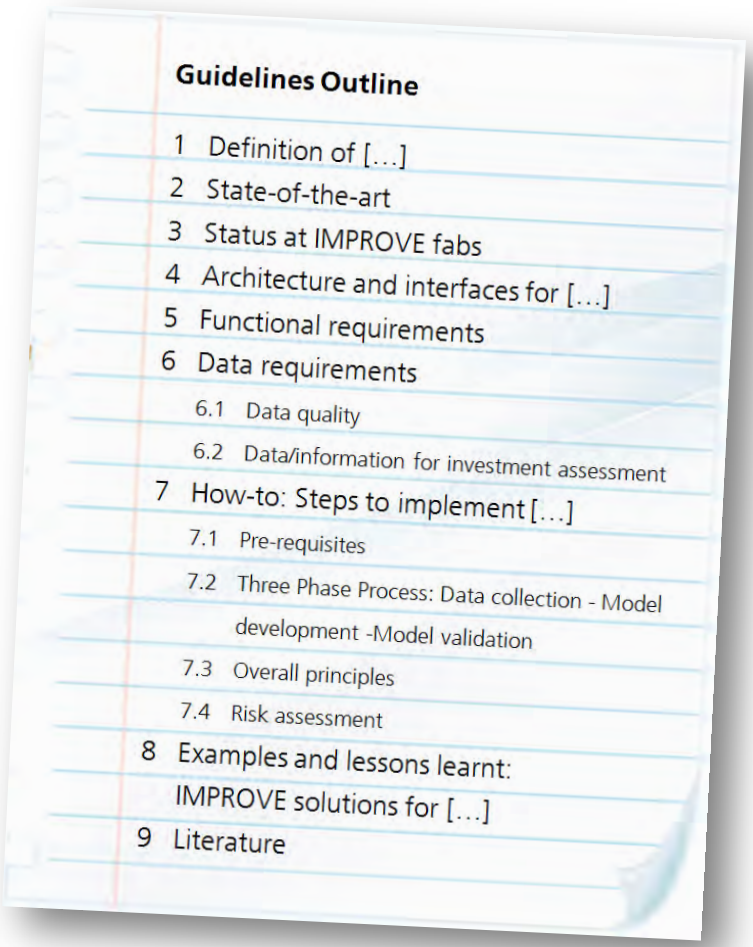
Summary of scientific and technical experiencies - Guidelines for implementation of VM, PdM, and fab-wide frameworks



Guidelines Outline

1 Definition of […]
2 State-of-the-art
3 Status at IMPROVE fabs
4 Architecture and interfaces for […]
5 Functional requirements
6 Data requirements
6.1 Data quality
6.2 Data/information for investment assessment
7 How-to: Steps to implement […]
7.1 Pre-requisites
7.2 Three Phase Process: Data collection - Model development -Model validation
7.3 Overall principles
7.4 Risk assessment
8 Examples and lessons learnt: IMPROVE solutions for […]
9 Literature

- Experiences and results from framework development and VM/PdM module integration and performance
- Generic approaches, individual methods, new solutions and best practices for VM/PdM algorithm development
- Requirements and overall principles
- Implementation steps

Conclusion

- Realization of a generic and reusable framework solution for implementation of VM and PdM into existing fab-environments
  - Compliance to a wide range of standards
  - Compatibility with different programming languages for VM/PdM algorithm realization
- Approach
  - Definition of VM/PdM as EE applications on a conceptual level and modeling of the EES as component system in UML
  - Framework acts as transparency layer between the fab architectures and the VM/PdM modules
- Realization, implementation, and test
  - Software realization by a service-oriented Java infrastructure
  - Framework implementation and test on VM and PdM applications at three IC manufacturers' sites; proof of good performance and adaptability

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