SEMICON Europa 2010 - TechARENA
- Automation and Process Control Session

Application of virtual metrology and predictive maintenance in semiconductor manufacturing

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With contributions from:
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Outline

- Motivation
- Virtual metrology (VM) and predictive maintenance (PdM)
  - Concept of VM for IC-manufacturing
  - Concept of PdM for IC-manufacturing
- Development of a fab-wide master framework
  - Approach for architecture development
  - Mapping of the framework to existing fab environments
- VM and PdM application examples
  - Prediction of etch depth
  - PdM approach for implant monitoring
- Conclusion

Motivation

Complex systems for process control in semiconductor manufacturing

- Comprising SPC, fault detection and classification, run-to-run control, and others
- Manifold approaches for the actual implementation:
  - Some fabs implement new control entities equipment by equipment
  - Others follow dedicated bottom-up or top-down approaches
- **Challenge**: How to implement new control paradigms in existing fab systems?

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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Concept of VM for IC-manufacturing

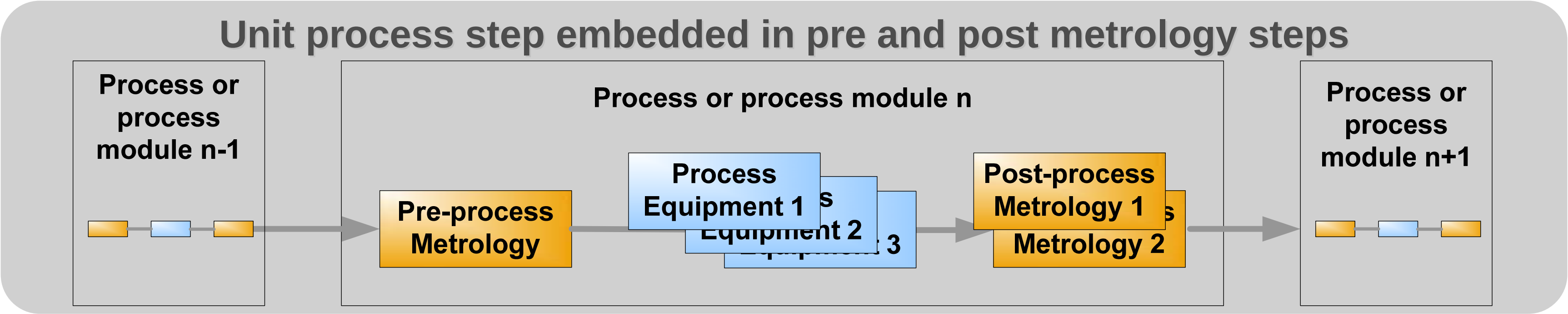
Current situation

- To ensure high process stability and high production yield, reliable wafer monitoring is required in current IC manufacturing
- Physical metrology of critical parameters by sampling of monitor or product wafers; no broad implementation of concepts like virtual metrology

Ideal control scenario and deficiencies

- Unit process monitoring and control should be performed in close time-frame after wafer processing (wafer-to-wafer)
- Even with fast in-line measurements time requirements for real-time process control are not met (parameters may not be measurable, measurements too expensive)

Unit process step embedded in pre and post metrology steps



VM objectives and benefits

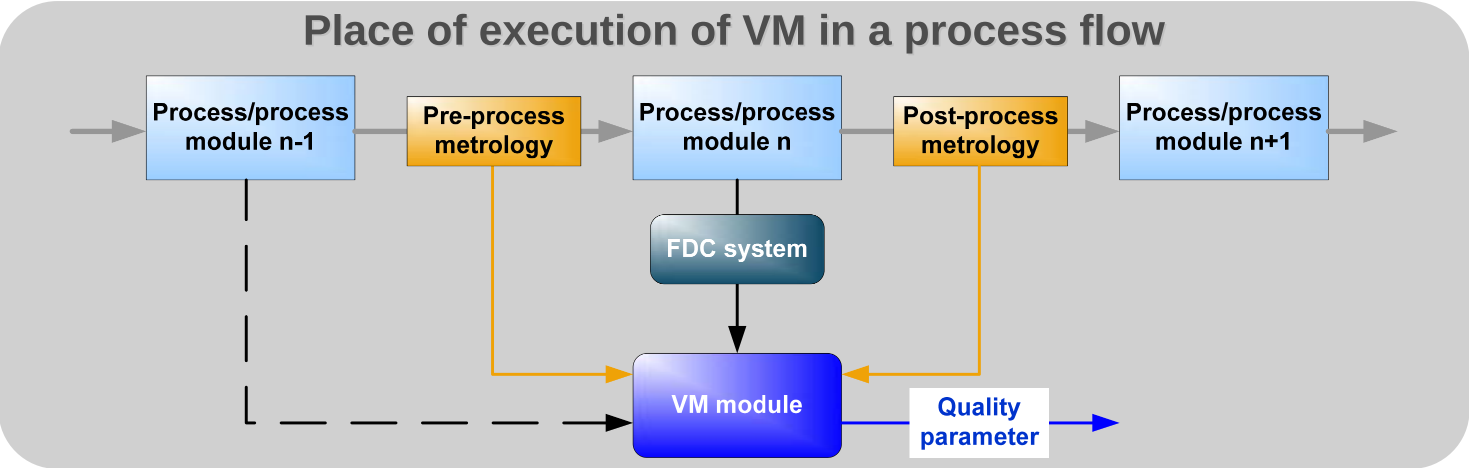
VM objectives

- Predict post process physical and electrical quality parameters of wafers and/or devices from information collected from the manufacturing tools including support from other available information sources in the fab

VM benefits

- Support or replacement of stand-alone and in-line metrology operations
- Support of FDC, run-to-run control, and PdM
- Improved understanding of unit processes

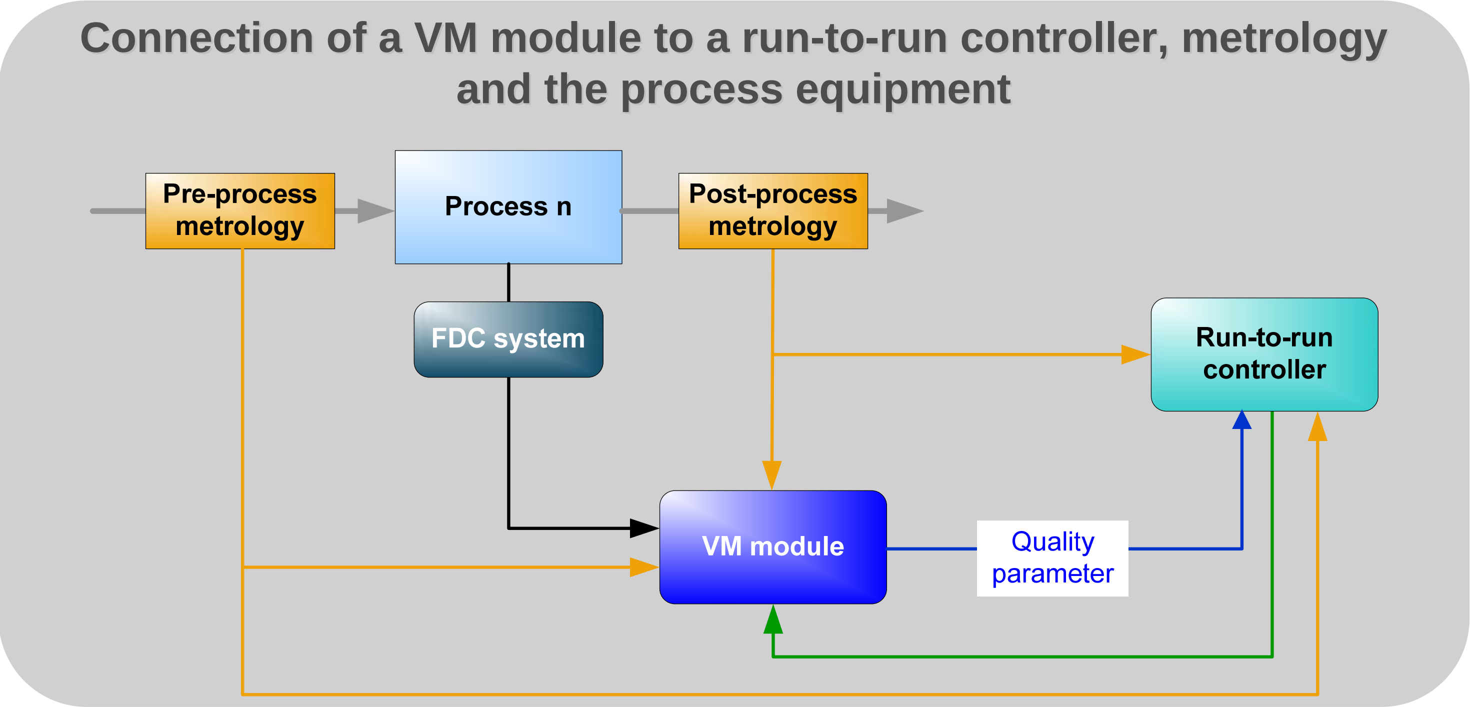
Place of execution of VM in a process flow



VM key requirements

Key requirements of a VM system

- Capability for estimation of the equipment state or wafer quality parameter within predefined reaction time
- Capability for integration into a fab infrastructure



Connection of a VM module to a run-to-run controller, metrology and the process equipment

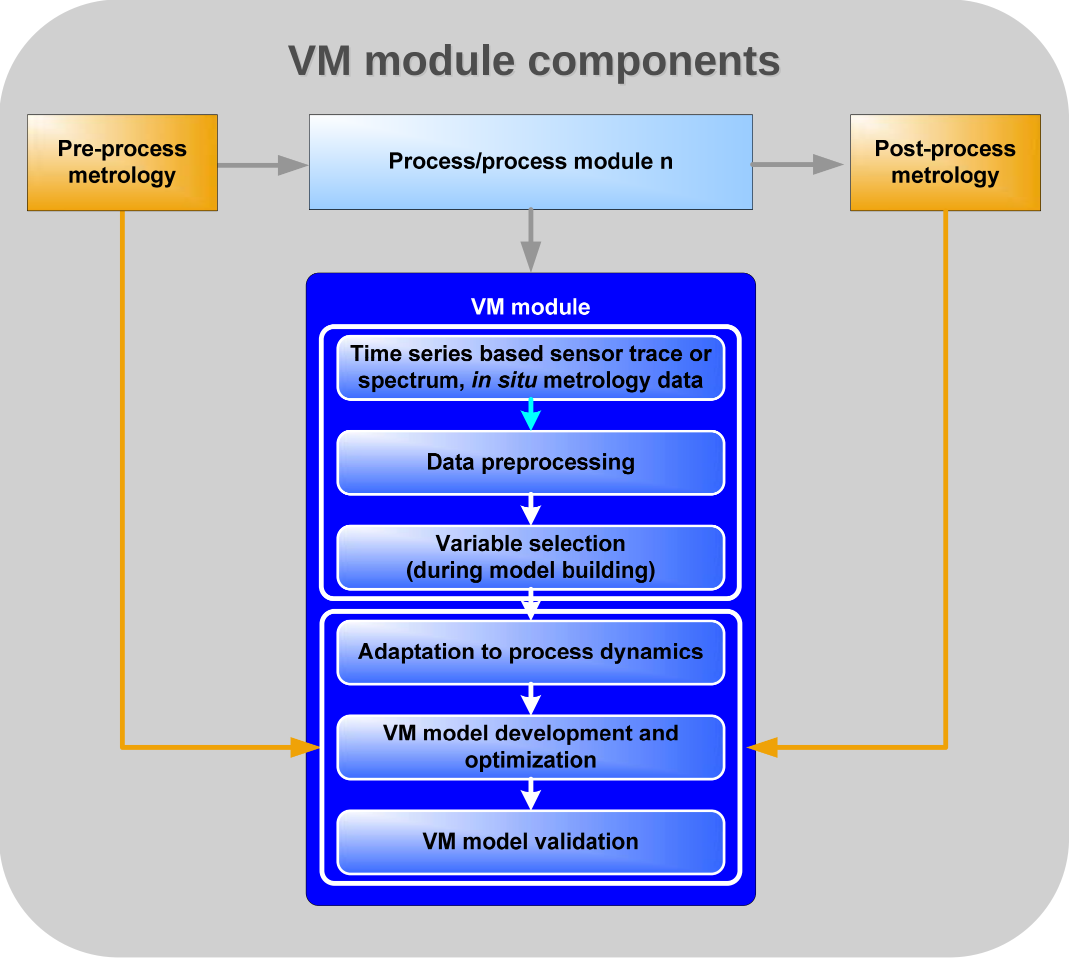
VM module requirements

VM module requirements

- Prediction of quality parameter and reliance indicators without metrology data, typically at wafer-to-wafer level
- Inclusion of metrology to control and adjust VM prediction and models

➔ Common quality parameters for equivalent process modules amongst different fabs

➔ Modular VM approach for efficient VM deployment possible



VM module components

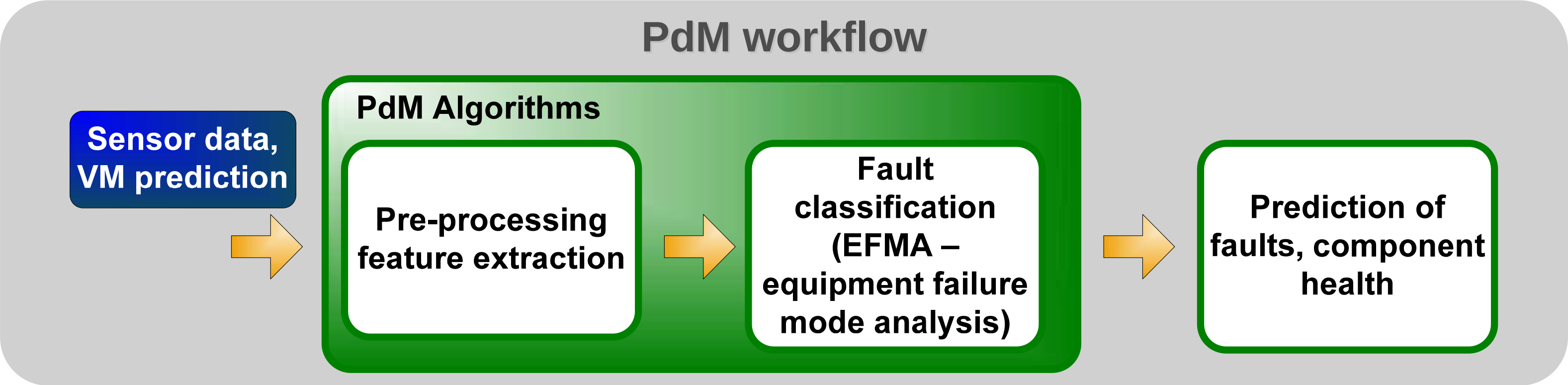
Concept of PdM for IC-manufacturing

Current situation of scheduled maintenance in semiconductor manufacturing

- Maintenance scheduled 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



PdM workflow

Sensor data, VM prediction

PdM Algorithms

Pre-processing feature extraction

Fault classification (EFMA – equipment failure mode analysis)

Prediction of faults, component health

PdM objectives, benefits and key requirements

PdM objectives

- Predict upcoming equipment failures or events, their root causes and corresponding maintenance tasks in advance

PdM benefits

- Improved uptime and availability - by reducing or eliminating unplanned failures
- Reduced operational cost – by enhanced consumable lifetimes and efficiency of service personnel
- Improved product quality – by eliminating degraded operation and tightening process windows
- Reduced scrap – by maintenance actions before a failure occurs

Key requirements of a PdM system

- Capability for reliable prediction of upcoming equipment failures, root causes and corresponding maintenance tasks
- Capability for integration into a fab infrastructure

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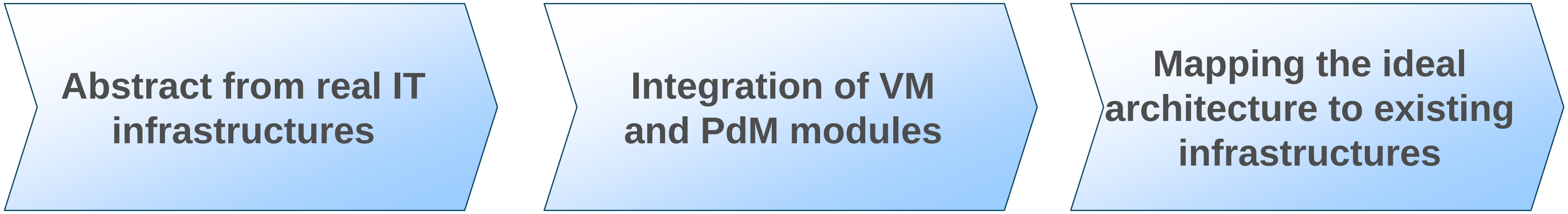
Architecture expectations and prerequisites

Development of an 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



Abstract from real IT infrastructures

Integration of VM and PdM modules

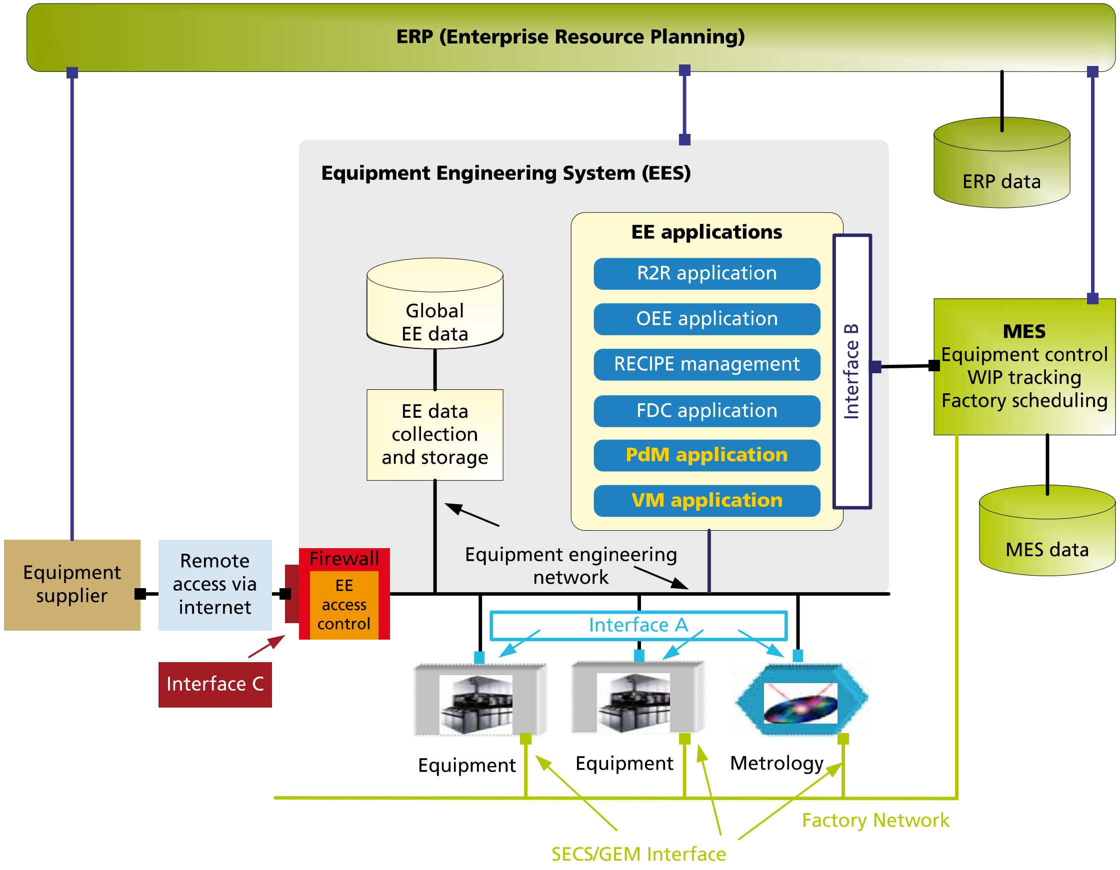
Mapping the ideal architecture to existing infrastructures

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

Concept for a generic VM and PdM implementation

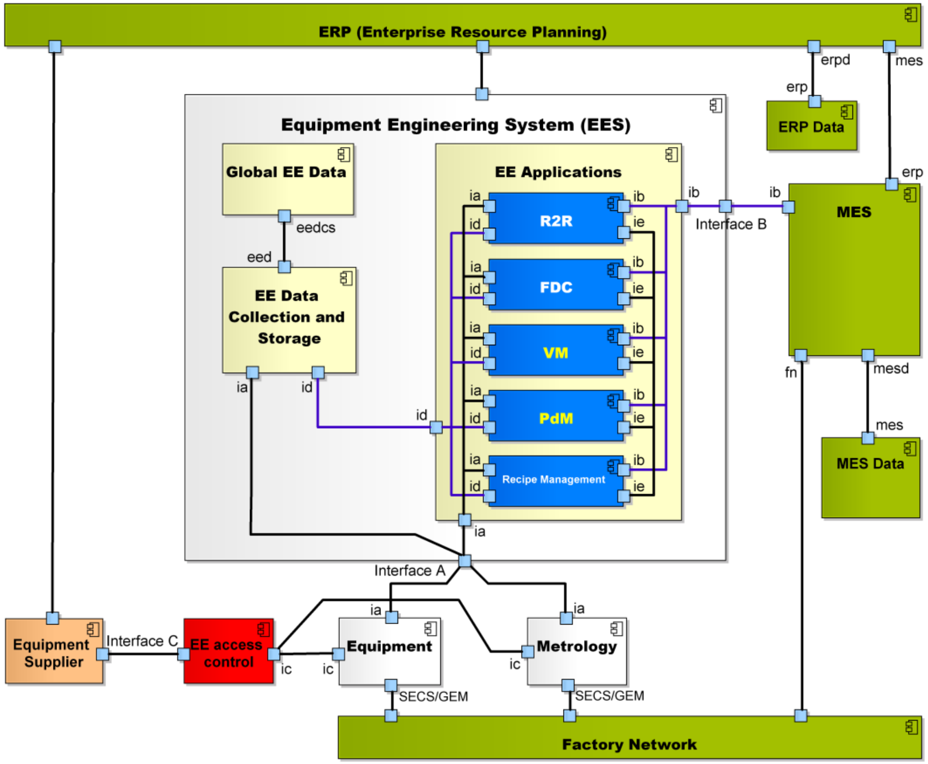
Definition of VM and PdM as EE applications on a conceptual level

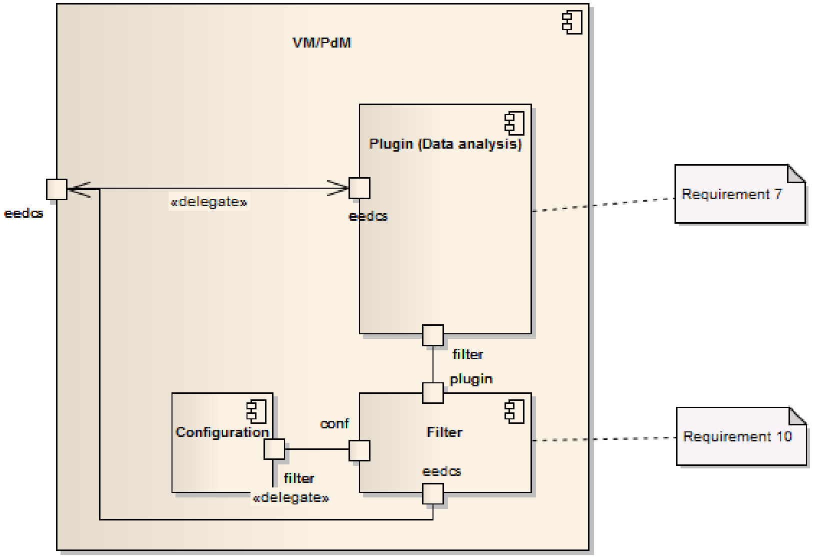


- Abstraction from existing fab infrastructures
- Application of existing SEMI standards possible, including especially interface A and interface B standards
- Extension of the existing SEMI standard E133 to include VM as an application note

Approach to a generic VM and PdM implementation

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





- Inclusion of configuration, data analysis, and filter modules as plug-ins
- Consideration of specific user requirements

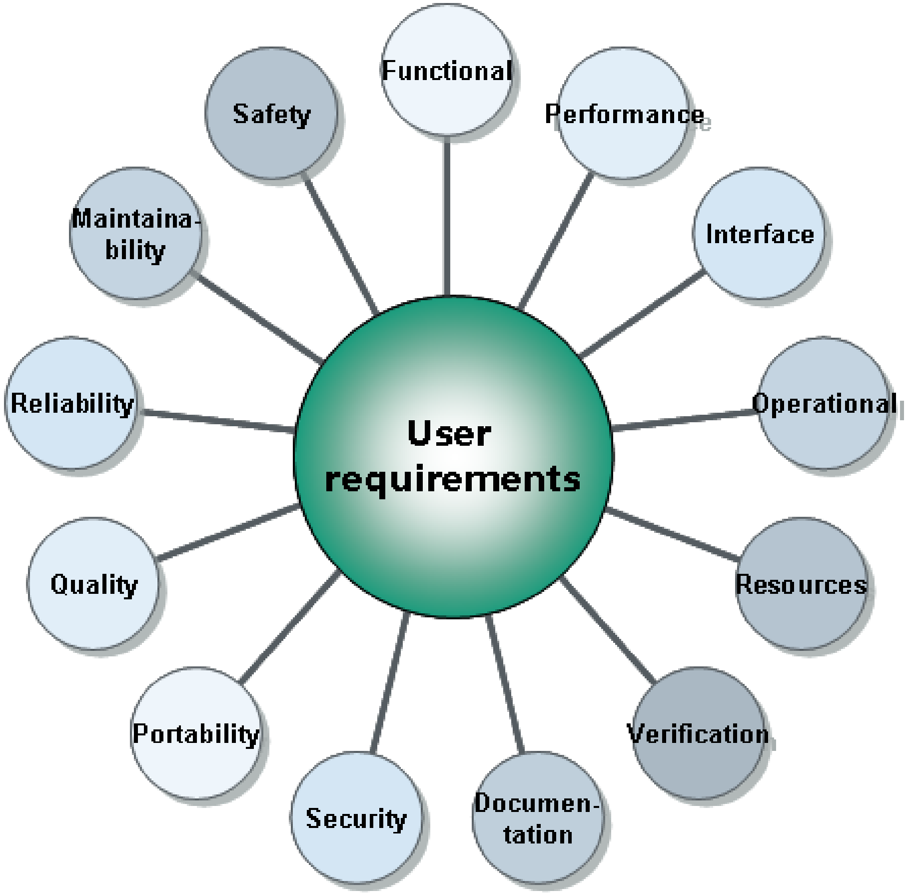
➔ Mapping to existing infrastructures

With contributions from the University of Augsburg

Consolidation of user requirements

Approach

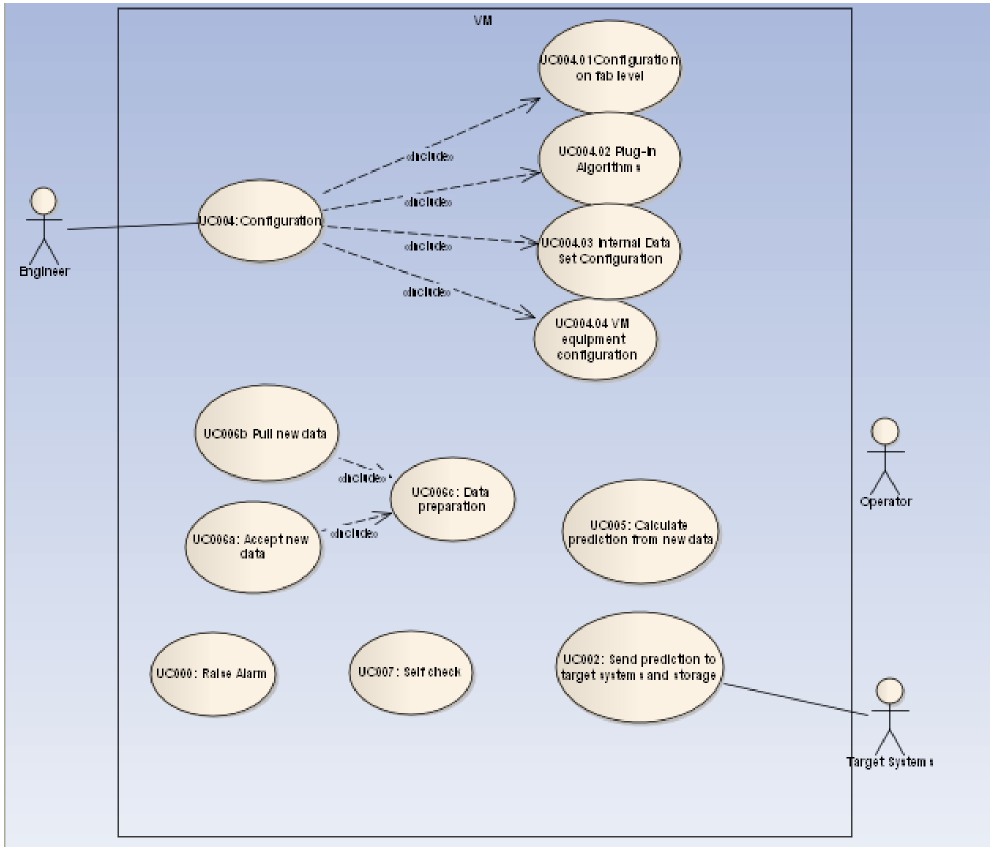
- Catalogue with quantifiable criteria and well defined classification of user requirements
- Criteria and classification cover the requirements for VM, PdM, and the framework architecture
- Collection of feed-back from all users involved in the IMPROVE project
- Consolidation of user requirements do develop a widely applicable architecture



With contributions from Critical Manufacturing

Mapping of the framework to fab environments

Use case development in a UML modeling environment



With contributions from Infineon Technologies AG

Approach

- Development of use cases based on user requirements in particular functional requirements
- Development of SW implementation based on use case (UC) descriptions
- Achievements:
  - Lead concept for the mapping of the ideal architecture to the fab environments developed
  - First framework realization available

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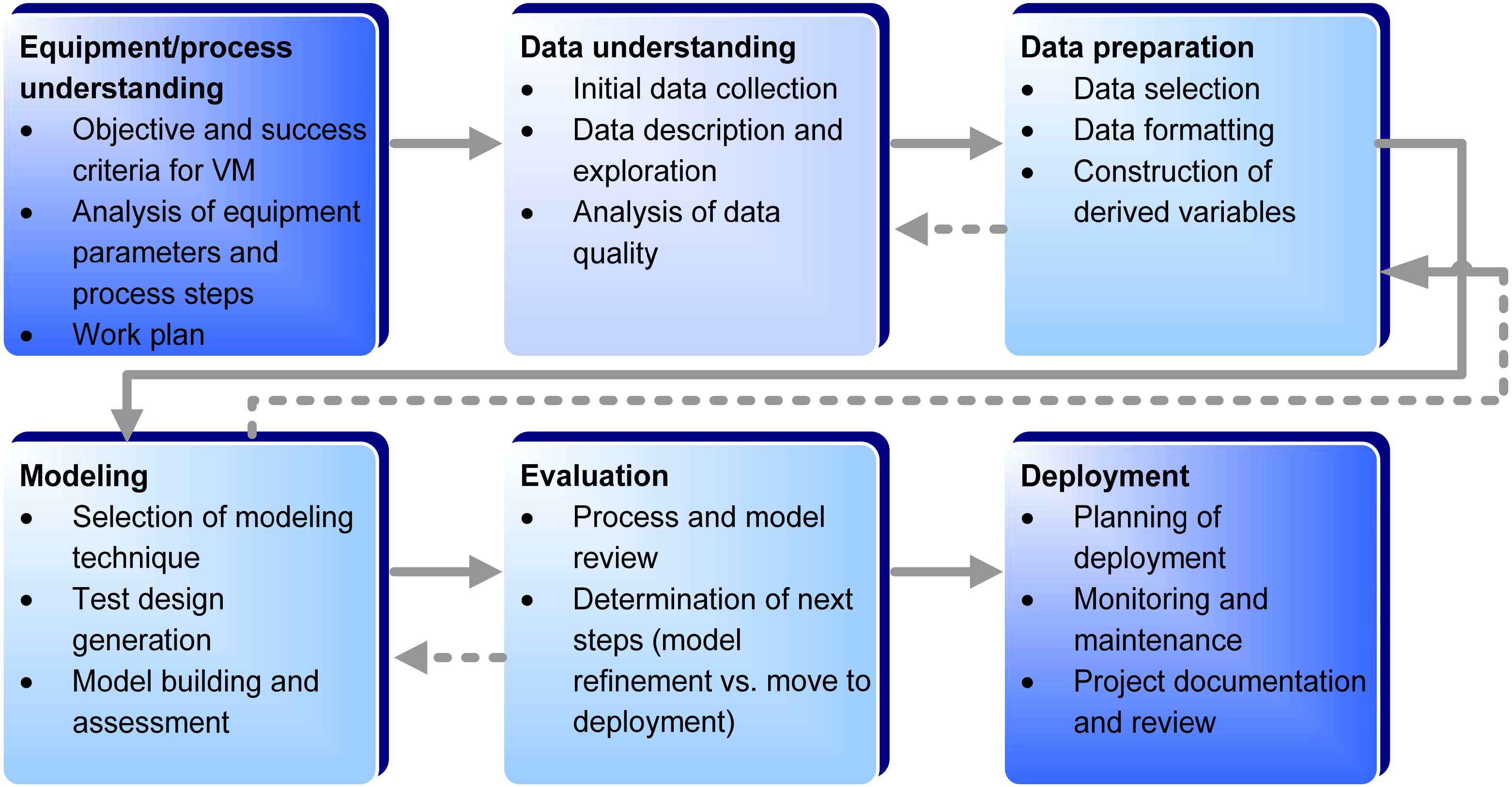
Systematic approach to VM development

Phases in VM development as adapted from the Cross-Industry Standard Process for Data-Mining (CRISP-DM)



Equipment/process understanding

- Objective and success criteria for VM
- Analysis of equipment parameters and process steps
- Work plan

Data understanding

- Initial data collection
- Data description and exploration
- Analysis of data quality

Data preparation

- Data selection
- Data formatting
- Construction of derived variables

Modeling

- Selection of modeling technique
- Test design generation
- Model building and assessment

Evaluation

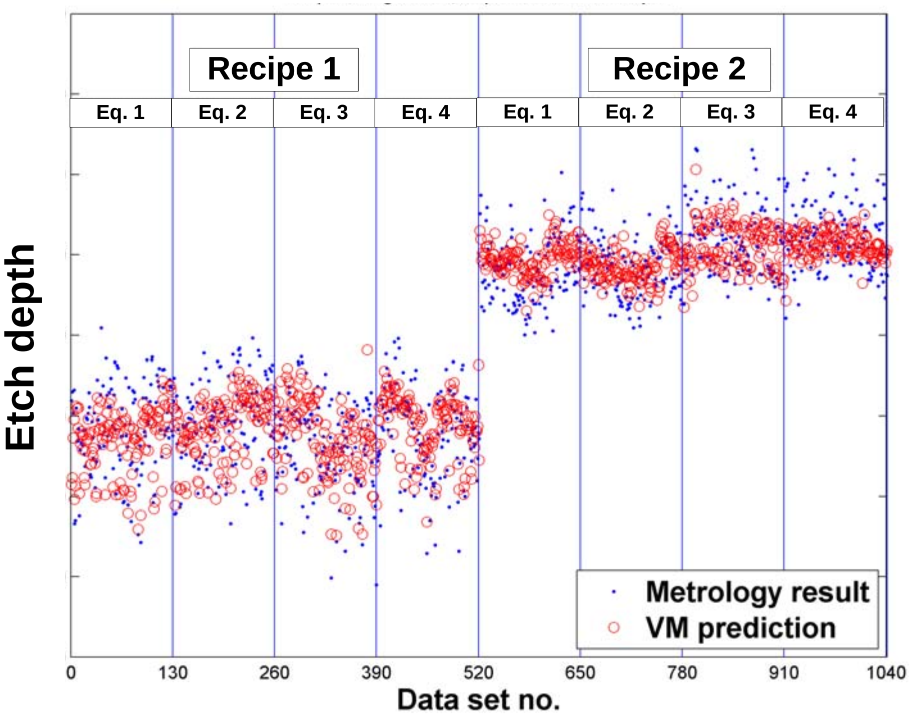
- Process and model review
- Determination of next steps (model refinement vs. move to deployment)

Deployment

- Planning of deployment
- Monitoring and maintenance
- Project documentation and review

VM example for etch process prediction

- Example etch process
  - Prediction of etched depth
  - Result: Prediction of etched depth possible
- Topics to be considered for architecture
  - Data mapping, data gaps, encoding of data, handling of process varieties
- Topics for VM assessment
  - Best model, complexity vs. robustness, deployment



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PdM approach for implant monitoring

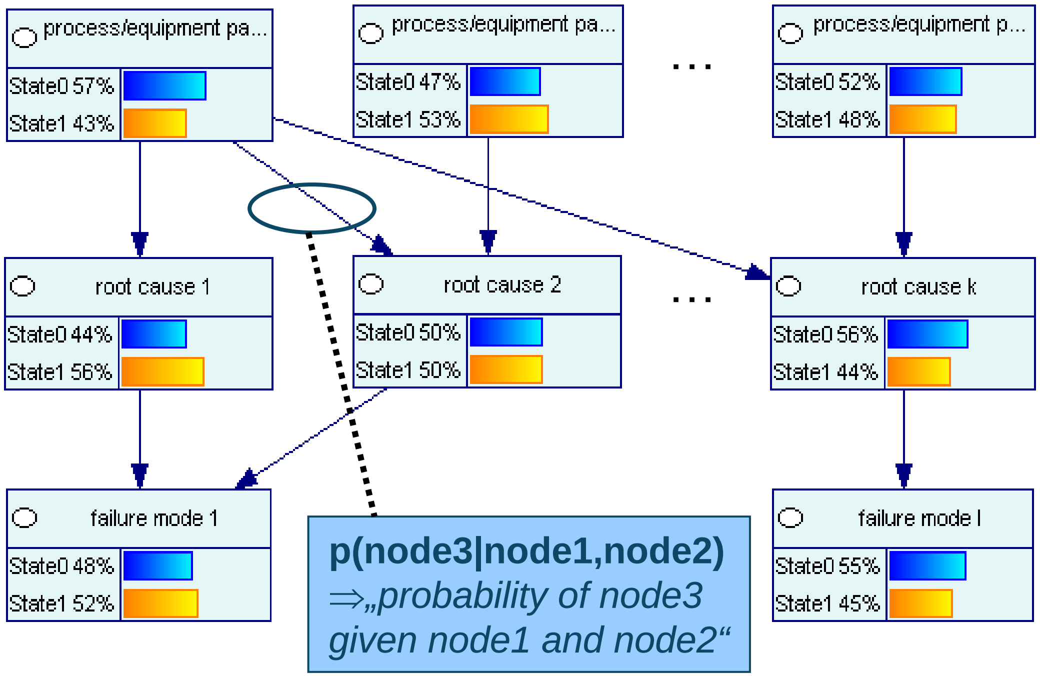
Applications addressed

- Prediction of failure time, failure mode and corrective actions
- Failure mode model of implantation equipment, in particular model for ion source lifetime prediction

Bayesian model concept for PdM

- Representation of states (parameters and data), e.g. pressure, sheet thickness, but also meta data, e.g. “thickness ok”
- Parent and child nodes: state of child nodes depends on state(s) of parent node(s)

Prediction of failure modes with Bayesian Networks



p(node3|node1,node2)
⇒„probability of node3 given node1 and node2“

Advantage: Predictability of failure modes to root causes and input parameter distributions

Conclusion

Achievements

- Need for a common architecture to integrate VM and PdM into the different existing fab systems (specific challenge in IMPROVE)
- Commonalities identified between an architecture for VM and PdM
- Modular approach towards an ideal architecture and user's current situation and requirements taken
- In parallel, development of optimized VM and PdM algorithms

Next steps in IMPROVE

- Assessment and consolidation of VM and PdM algorithms
- Further development and refinement of SW framework including experiences from VM and PdM solutions

Acknowledgment

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