Architecture for the Integration of Virtual Metrology and Predictive Maintenance into Existing Fab Systems

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Georg Roeder, Martin Schellenberger, Markus Pfeffer, *Fraunhofer IISB, Erlangen, Germany*
Andreas Kyek, *Infineon Technologies, Regensburg, Germany*
Alexander Knapp, Heribert Mühlberger, *University of Augsburg, Germany*

Architecture for the Integration of Virtual Metrology and Predictive Maintenance into Existing Fab Systems

- 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
  - UML model of an ideal architecture for VM and PdM
  - Consideration of user specifications
- 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** to integrate VM and PdM into the different existing fab systems

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Concept of VM for IC-manufacturing
Context and current situation

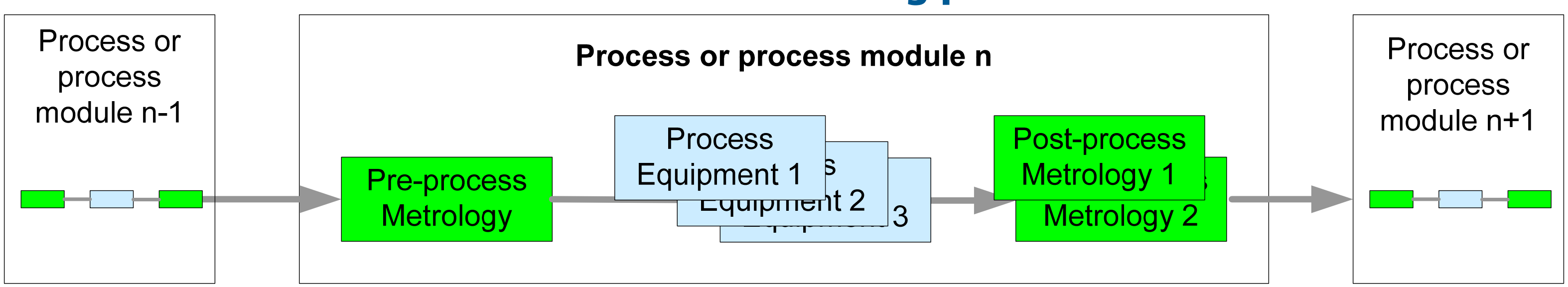
Current situation

- To insure 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, e.g. on a wafer-to-wafer basis
- Even with fast in-line measurements time requirements and confidence levels for real-time process control are not met; relevant parameters may not be measurable

Unit processes step embedded in pre and post metrology steps and the manufacturing process.

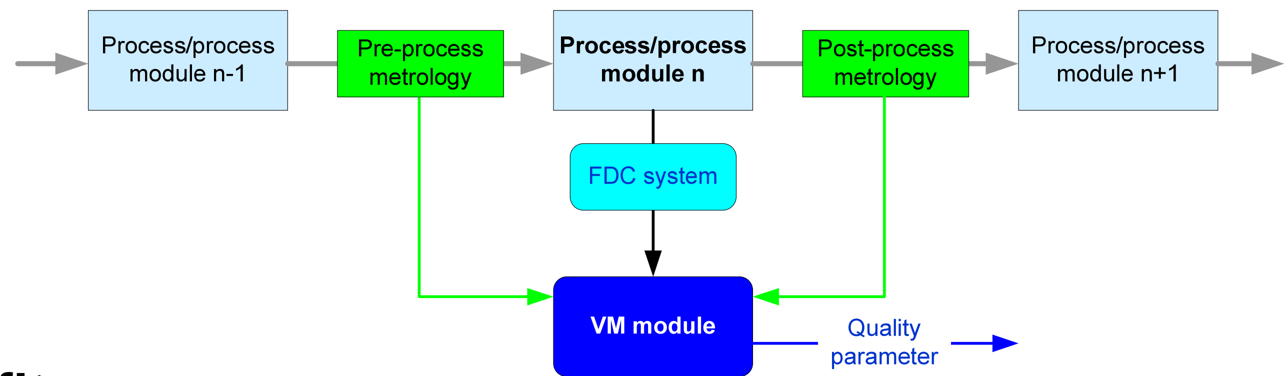


Concept of VM for IC-manufacturing
VM objectives and benefits

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

Place of execution of VM in a process flow



VM benefits

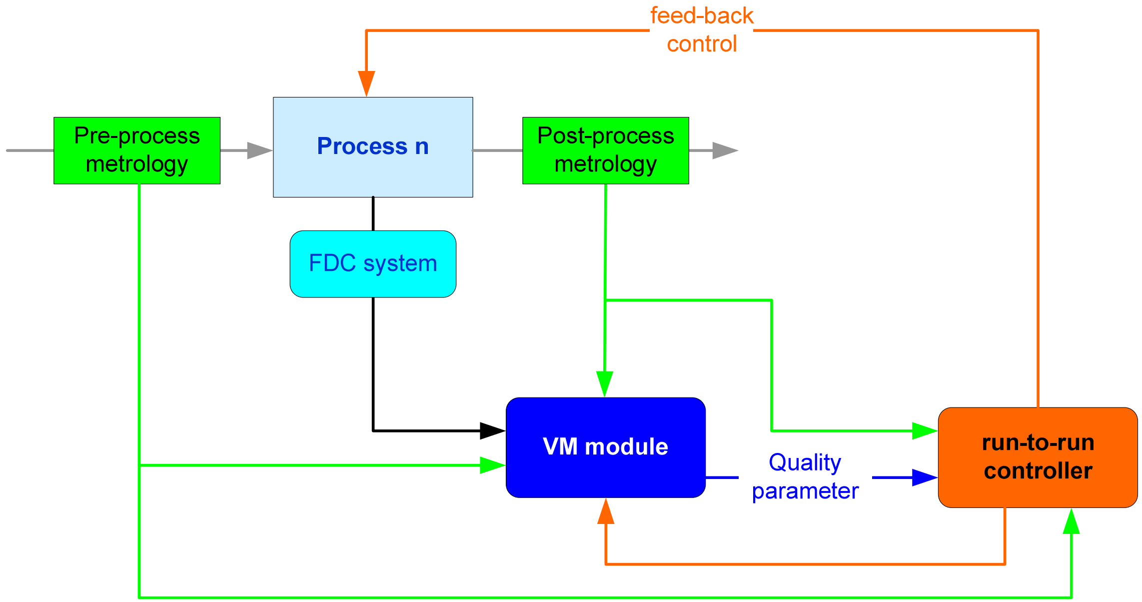
- Support or replacement of stand-alone and in-line metrology operations
- Support of FDC, R2R control, and PdM
- Improved understanding of unit processes

Concept of VM for IC-manufacturing
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



Concept of PdM for IC-manufacturing
Context and current situation

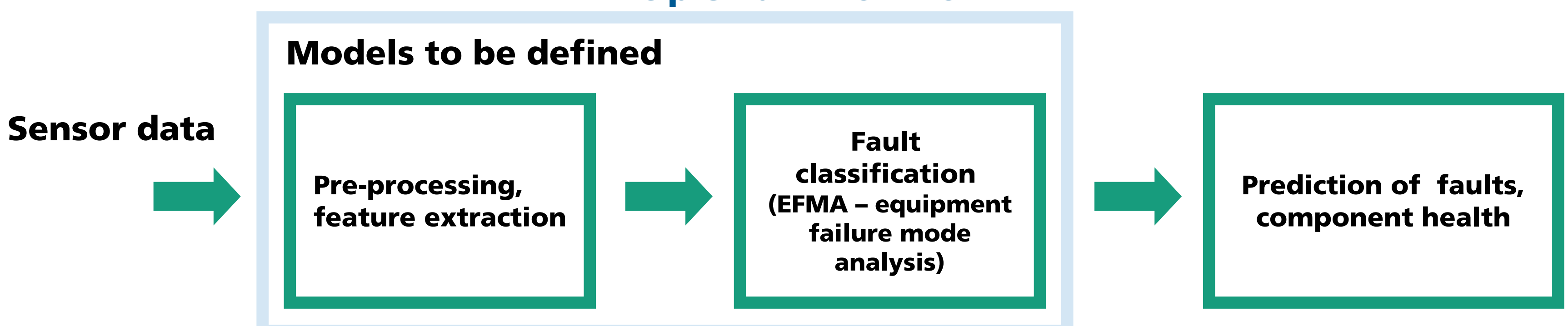
Current situation of scheduled maintenance in semiconductor manufacturing

- 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.

Principle PdM workflow



Concept of PdM for IC-manufacturing
PdM objectives, benefits and key requirements

PdM objectives

- Predict upcoming equipment failures or events, their root causes and corresponding maintenance tasks in advance
- Calculate an equipment health factor – a KPI (key performance indicator) for the current condition of the processing equipment

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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Approach for architecture development
Architecture expectations and prerequisites

Development of an ideal 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

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
- Improved communication

Prerequisites

- Ideal architecture anticipates high data availability and high polling frequencies
- Limitations for the mapping from the ideal to a real architecture may exist

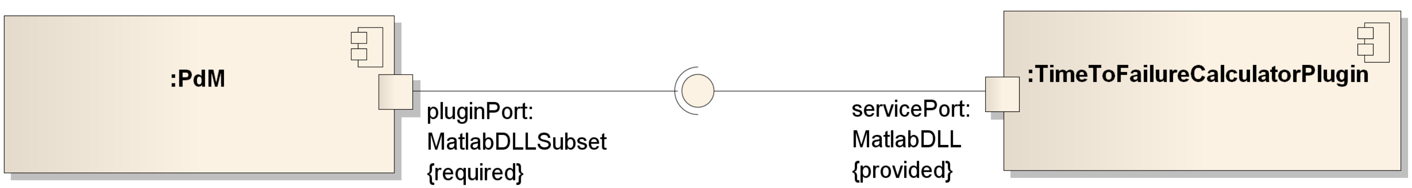
Approach for architecture development
Unified Modeling Language (UML)

- UML is the “lingua franca” of software engineering
  - Developed since 1995
  - Standard of the object management group
  - Current version 2.2
- Features a rich set of diagrams both for static structure and dynamic behavior
  - Classes, components, deployments, …
  - Use cases, activities, state machines, …
- Use for communication and documentation
  - Making requirements precise
  - Discussion of architectural alternatives
- Tool support
  - Enterprise Architect, Rational Rose, MagicDraw, …
  - Unified and consistent view on project

Approach for architecture development
Unified Modeling Language (UML)

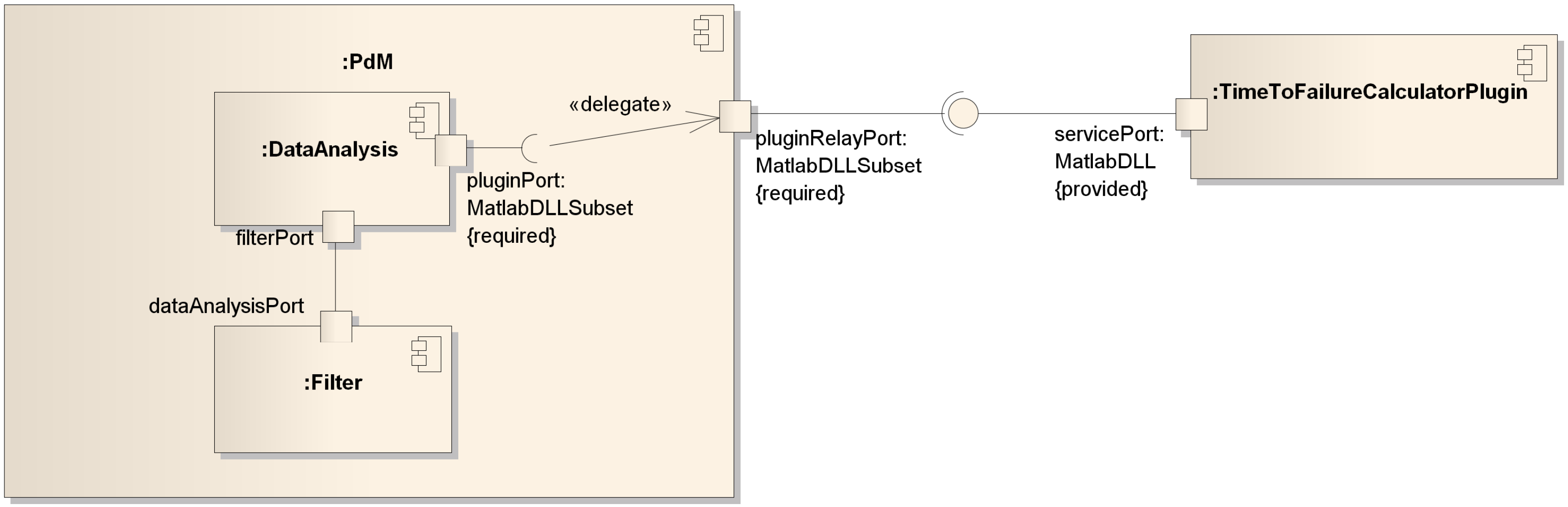
- Components are strongly encapsulated behaviors
- Ports are “windows of components” which regulate any interaction of components with their environment
- Connectors link components via their ports and enable communication
- “Provided ports” are ports which specify a provided interface (ball-notation) and thus a set of types of messages that are accepted by the port
- “Required ports” are ports which specify a required interface (socket-notation) and thus a set of types of messages that have to be accepted by the opposite port(s) for proper functioning
- Ball- and socket-notation can be plugged together to form an assembly connector
- Ports specifying both required and provided interfaces are termed “complex”

A UML assembly connector linking two component ports



Approach for architecture development
Unified Modeling Language (UML)

A hierarchically structured UML component diagram

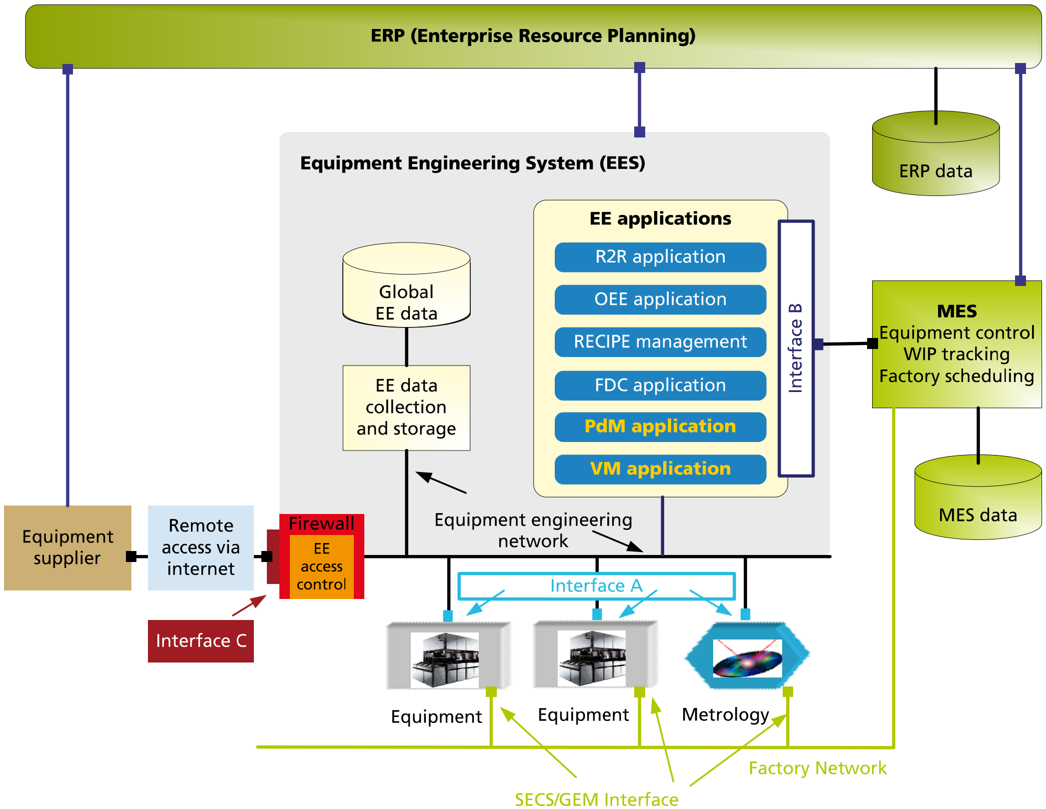


- A component can contain an assembly of other components linked by connectors
- Delegation connectors are used to model the hierarchical decomposition of behavior
- Services required by subcomponents may be delegated to a “required port” of the encompassing hierarchical component
- Services provided by ports of the encompassing component may be delegated to and realized by a “provided port” of a subcomponent

UML model of an ideal architecture for VM and PdM

Concept for a generic VM and PdM implementation

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

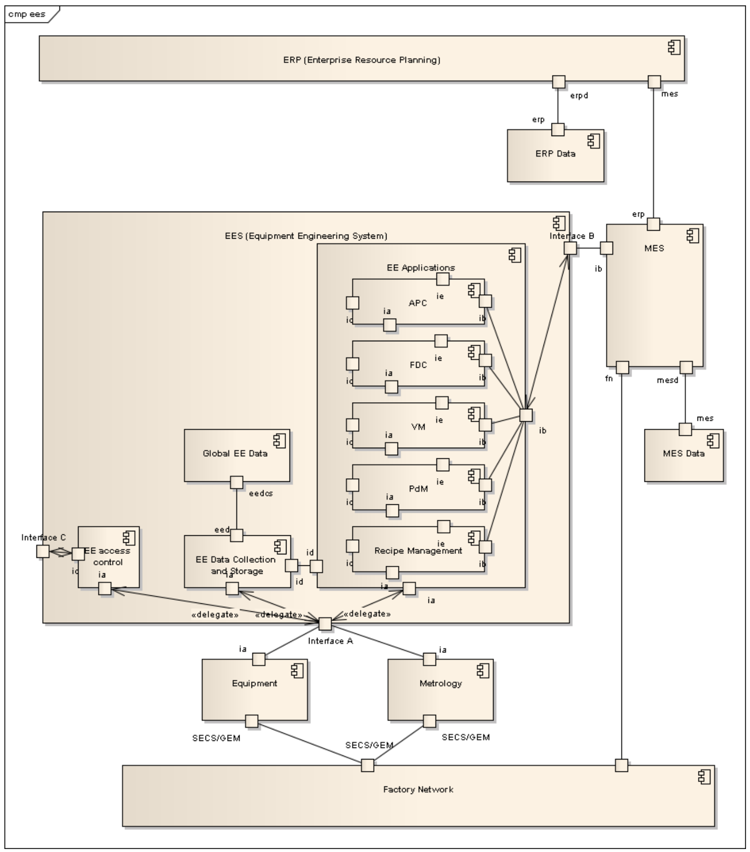


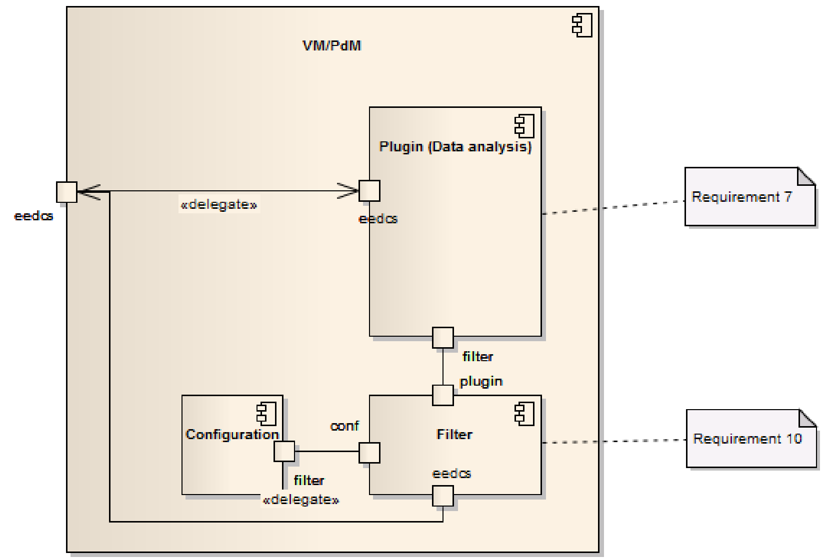
- Application of existing SEMI standards possible, including especially interface A and interface B standards

UML model of an ideal architecture for VM and PdM

Approach towards a generic VM and PdM implementation

UML description of the EE system as "ideal" architecture and of a generic VM/PdM module





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

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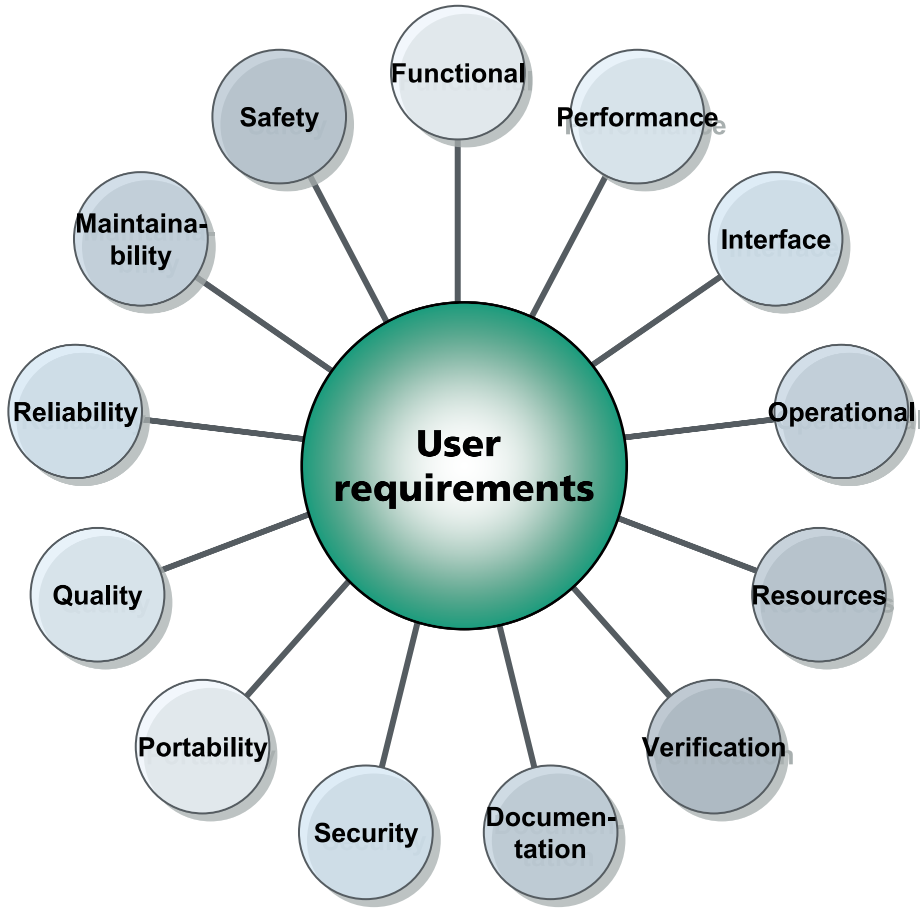
Consideration of user specifications
Consolidation of different user requirements

Approach taken

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



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Consideration of user specifications
Quantification of user specifications

Criteria for quantifiably requirements specification

- Specific - Without ambiguity, using consistent terminology, simple and at the appropriate level of detail
- Measurable - It must be possible to verify that this requirement has been met
- Attainable - Requirements must be technically feasible
- Realizable - Requirements must be realistic, given the resources
- Traceable - Requirements need to be traceable from conception through specification, design, implementation, and test

Conclusion

- Need for a common architecture to integrate VM and PdM into the different existing fab systems is obvious
- Commonalities identified between an architecture for VM and PdM
- Balance between theoretical approach towards an ideal architecture and user's current situation and requirements is envisaged
- The modular approach is the key to meet the requirements of exploitation in different fabs with different SW environments
- The use of UML provides the necessary frame for architecture development in a geographically spread working group as we face it in IMPROVE

Next steps in IMPROVE

- Mapping of user requirements with architecture
- Demonstration in real fab environment

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