A Model Driven Approach for Requirements Engineering of Industrial Automation Systems

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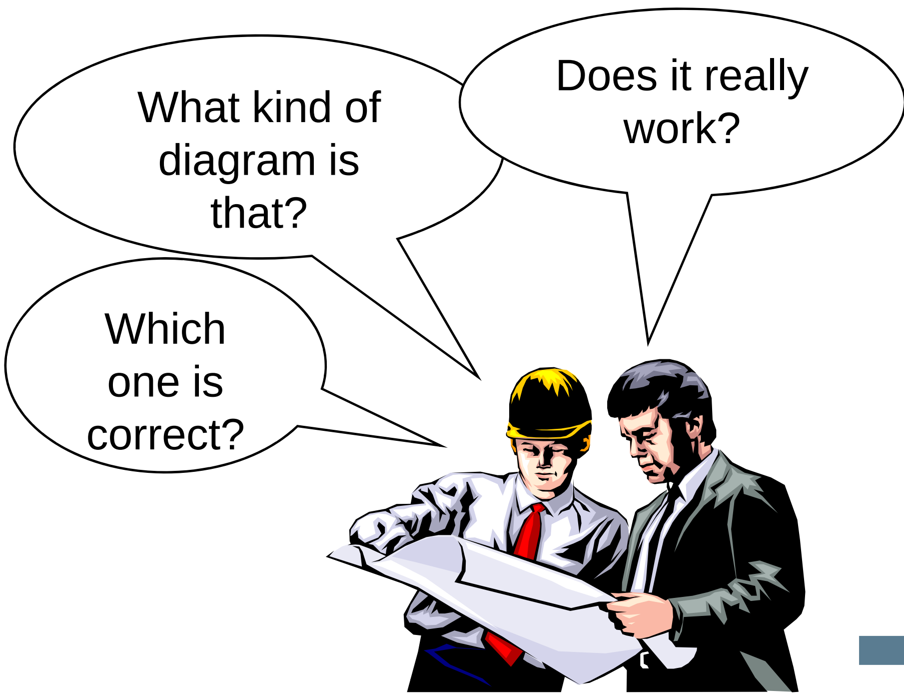
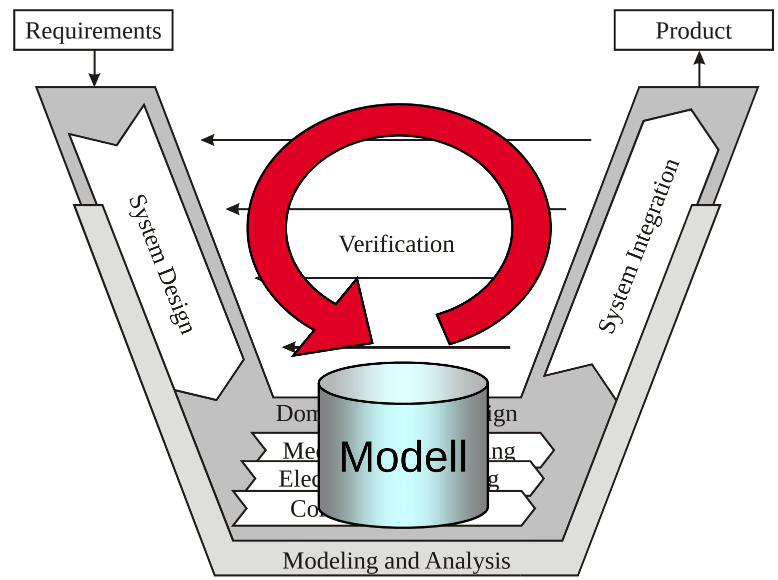
- **Introduction**
- Model Driven Requirements Engineering
- Case Study: Hydrostatic Press System
- Conclusion and Outlook

Motivation

What are the problems?

- Textual specifications ➔ Inconsistencies between documents
- No universal modeling language ➔ Misunderstanding among different disciplines
- Manuel verification process ➔ Hard to detect the design error at the early stage





V-Model according to VDI 2206

➔ **Model Driven Requirements Engineering**

Introduction

- Model Driven Requirements Engineering (MDRE)
  - *Development method providing the means for using **models** to direct the course of understanding, design, construction and deployment.* **[OMG: MDA Guide]**

- The deficiencies of **SysML** as the modeling language in MDRE
  - Requirement constructs are not sufficiently defined
  - It is not capable to describe dynamic models

Goals of this work

- Analyze the applicability of MDRE in the field of industrial automation
- Extend the SysML requirement constructs
- Integration with Modelica by using ModelicaML

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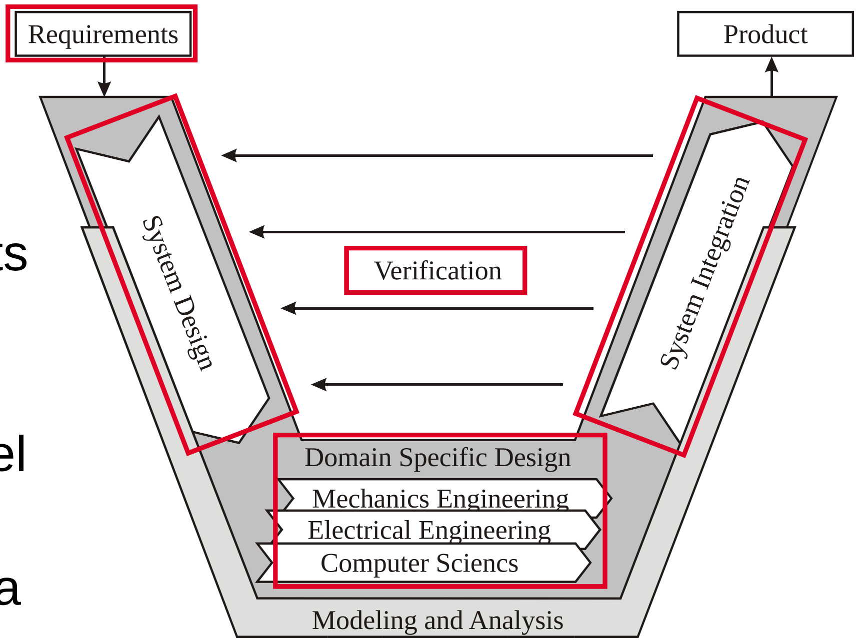
Application of MDRE in Industrial Automation

- Modeling languages and tools used in each design phase
  - **Requirements:** SysML requirement constructs extended by the MDRE4BR profile
  - **System design:** SysML diagrams used to model the descriptive system design
  - **Domain-specific design:** domain-specific drawing tools reflecting the SysML concepts is desired
  - **System integration:** Modelica models created or generated from the design model by using ModelicaML
  - **Verification:** run the simulation of Modelica model to verify the system design against system requirements



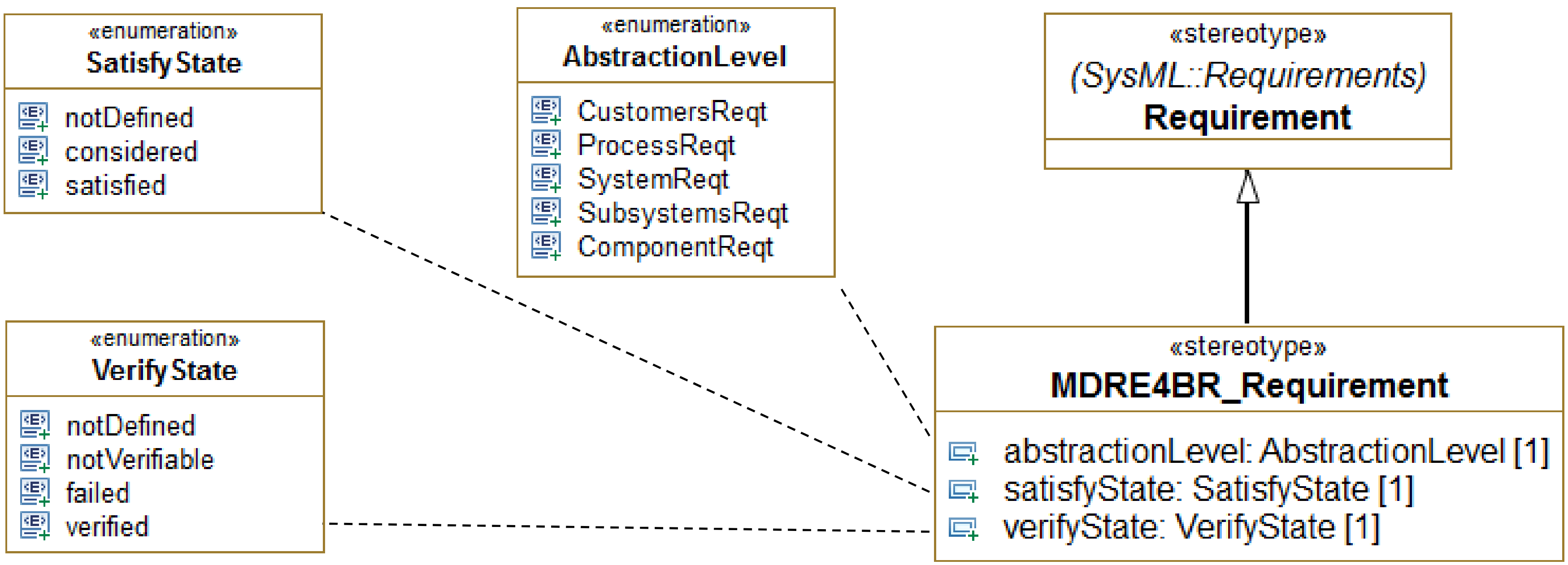
MDRE4BR Profile

- The shortcomings of SysML requirements constructs
  - No classification of requirements
  - Limited traceability concept
  - No executable test cases

- Objective of the MDRE4BR profile
  - UML profile to extend the SysML requirements constructs
  - Enhanced definitions of requirements
  - Extend the traceability links
  - Verification process compliant with the development of industrial automation systems
  - Integration with Modelica

Definition of Requirements

- **Abstraction Level** helps to cluster the requirements in a break down structure
- **Satisfy State** check the coverage of the requirement
- **Verify State** identifies the verification results



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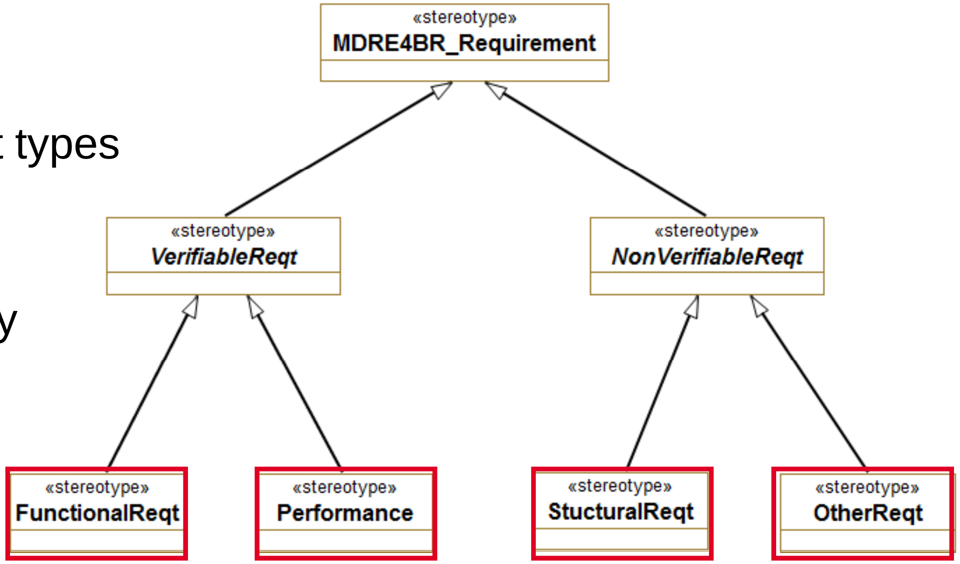
Classification of Requirements

- Classification
  - A *functional requirement* is a requirement that should produce an expected reaction to a given stimuli.
  - A *performance* is a requirement to check whether a system variable such as timing, speed, volume or throughput is in a desired range.
  - A *structural requirement* is a requirement which describes the structural demand of the stakeholder.
  - A *other requirement* is all the other types of not-analytically-verifiable requirements

- Reasons for classification
  - Different attributes for different types
  - Processed differently in the verification stage
  - Basis for the further traceability concept



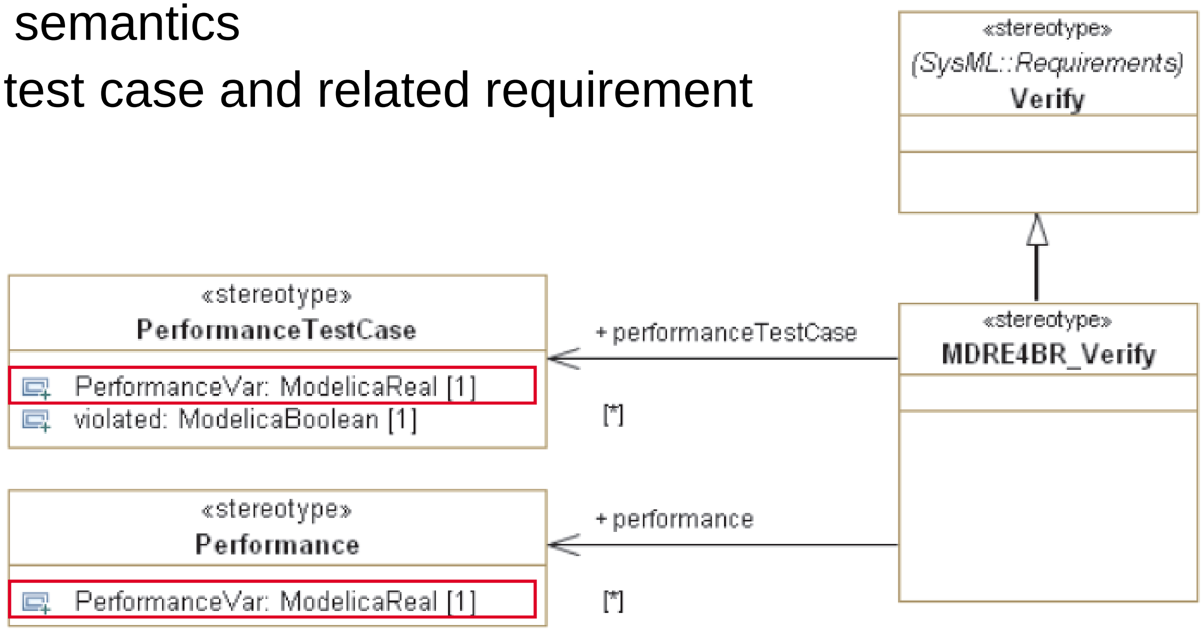
[Glinz, 2007]

Traceability of Requirements

- Traceability in SysML
  - Requirement to requirement: (copy, containment, deriveReqt)
  - Requirement to design element: (**satisfy**, trace, refine)
  - Requirement to test case: (**verify**)

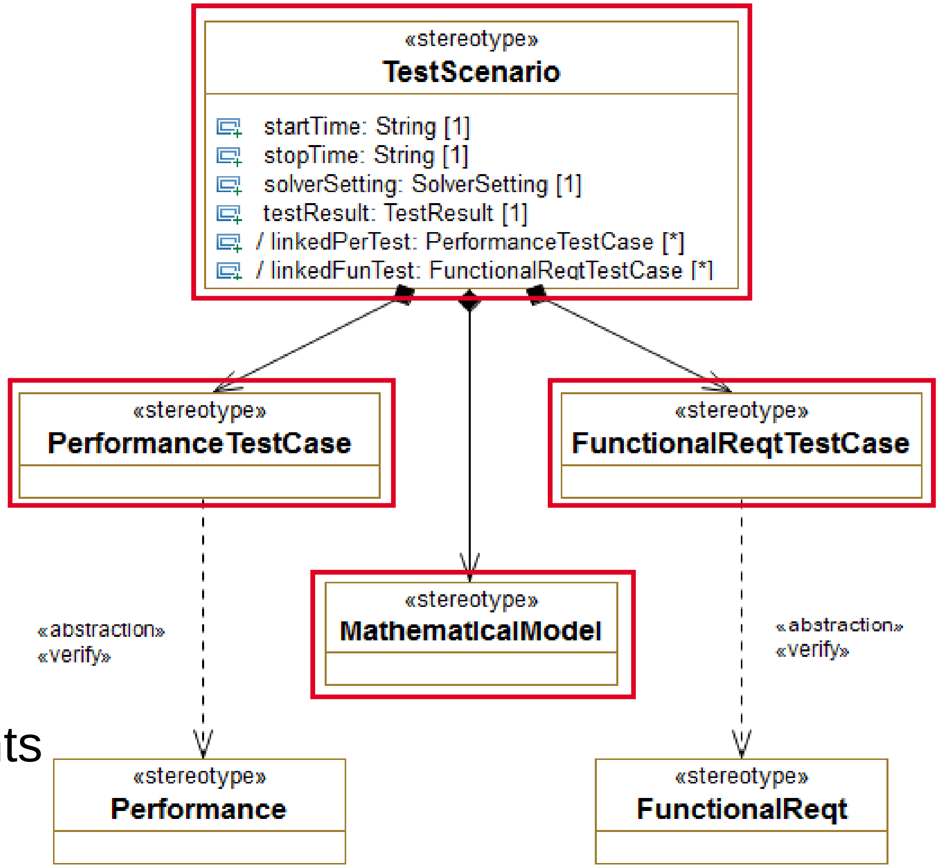
- Concept to extend the **satisfy** and **verify** relationships
  - More precisely defined semantics
  - Binding of variables of test case and related requirement with verify relation

- Open issue
  - Trace back the verification results to requirement automatically



Verification of Requirements

- New stereotypes
  - Performance Test Case
  - Functional Requirement Test Case
  - Test Scenario
  - Mathematical Model
- Verification process
  - Define a test scenario
  - Select a mathematical model
  - Select the associated test cases
  - Run the simulation
  - Update the *Verify State* in requirements
- Open issue
  - Define a traceability link between test cases and mathematical model to automate the variables binding



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Case Study: Hydrostatic Press System

- The tasks
  - Analysis of customer requirements
  - Modeling of customer requirements
  - Modeling of system design
    - System structures
    - System behaviors
    - Domain-specific design
  - Modeling of the analytical models
  - Verification of systems design against requirements

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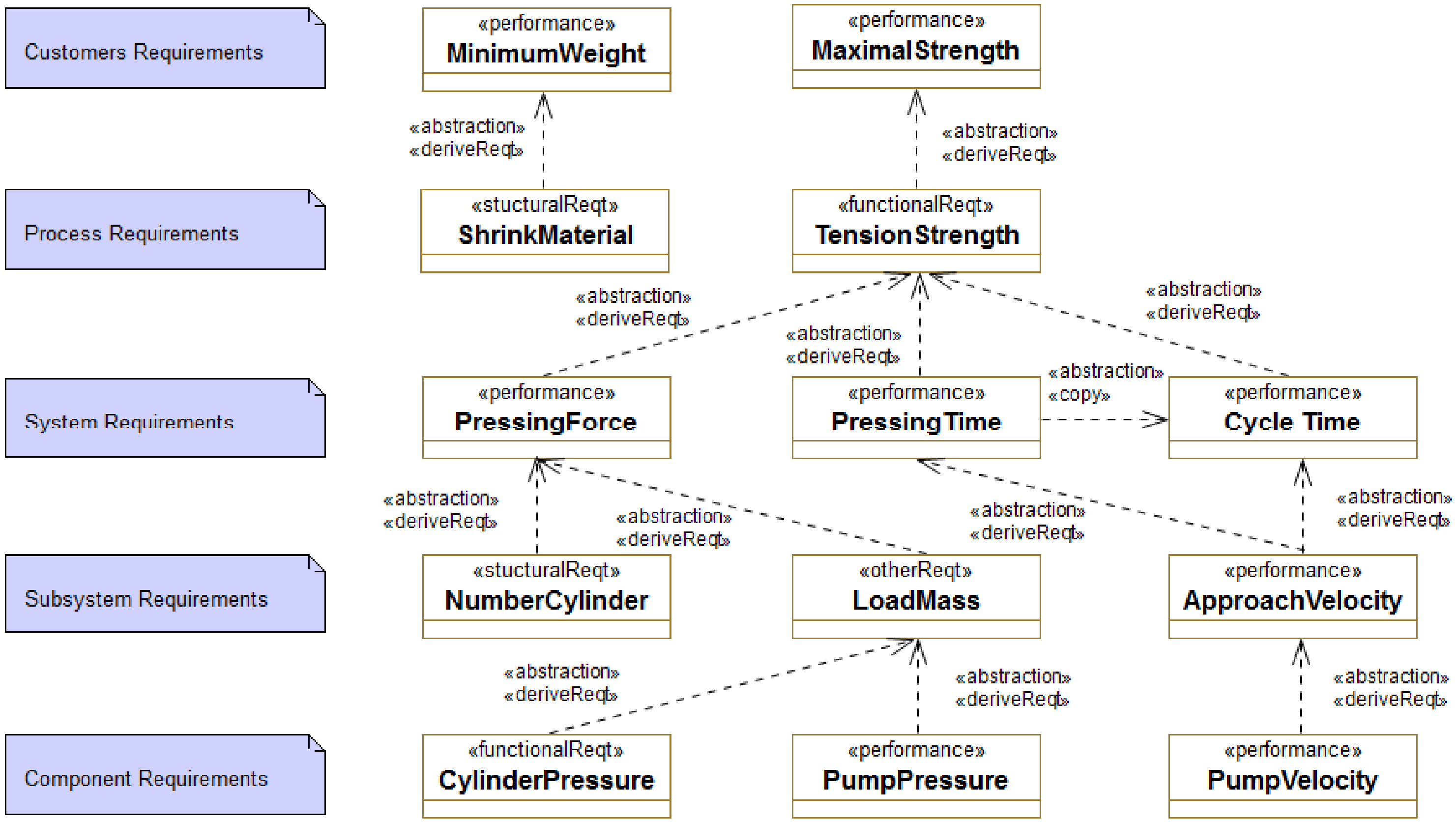
Step 1: Capture and Refine Requirements

- Capture the customer requirements as stereotyped requirements according to the classification
- Refine the higher level requirements to lower level requirements



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Step 1: Capture and Refine Requirements

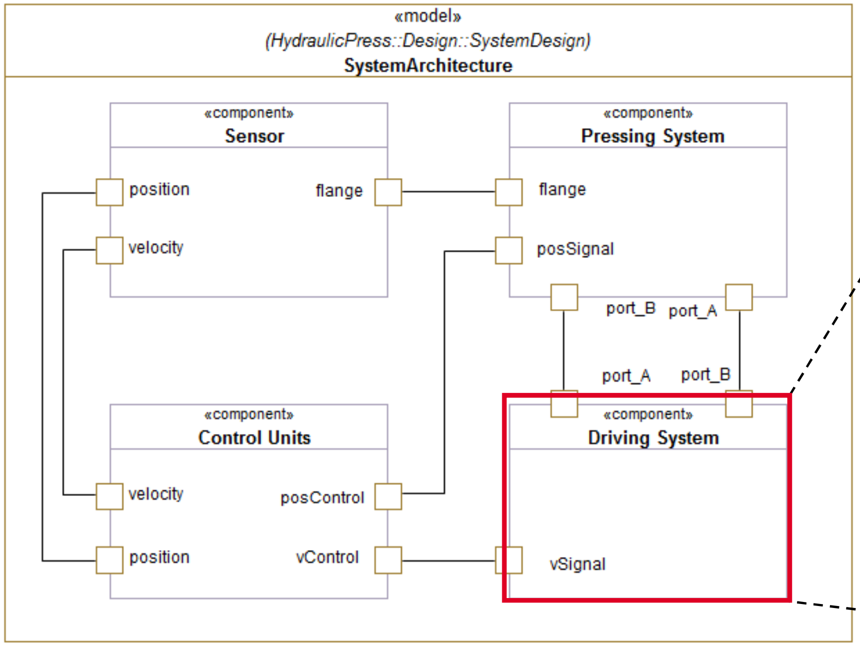
- Capture the customer requirements as stereotyped requirements according to the classification
- Refine the higher level requirements to lower level requirements

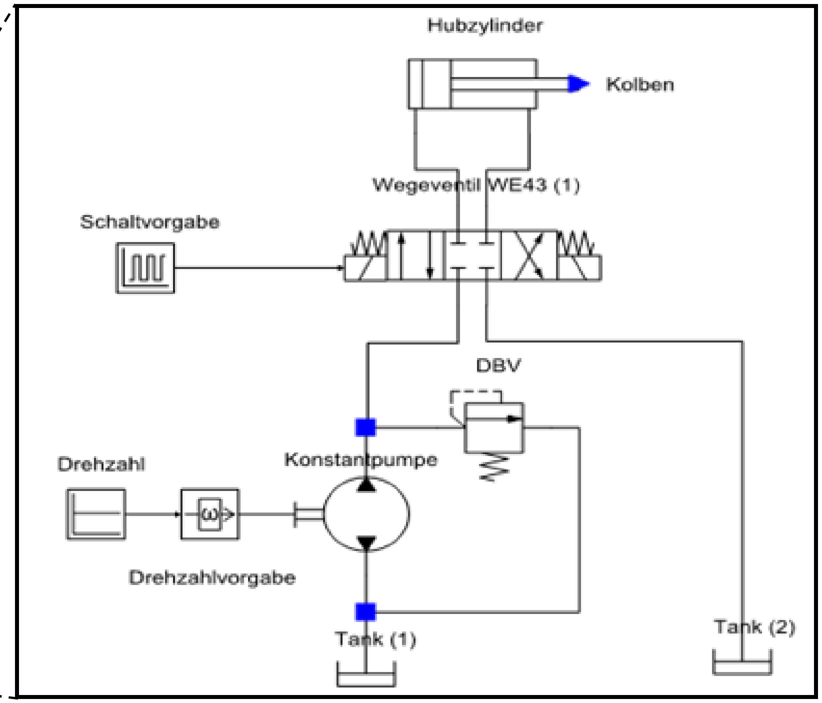
Remarks:

- The requirements can be structured systematically using different abstraction levels and classifications

Step 2: Create System Design Models

- System design: create the structural and behavioral model with SysML diagrams
- Domain-specific design: create the detailed design model in a domain-specific drawing tool





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Step 2: Create System Design Models

- System design: model the structural and behavioral model with SysML diagrams
- Domain-specific design: model the detailed design model in a domain-specific drawing tool

Remarks

- The system design process is well supported by SysML
- SysML is not suited for the domain-specific design
- Tool support for the domain-specific design with the extension that it can also reflect SysML constructs (stored as SysML model) is desired

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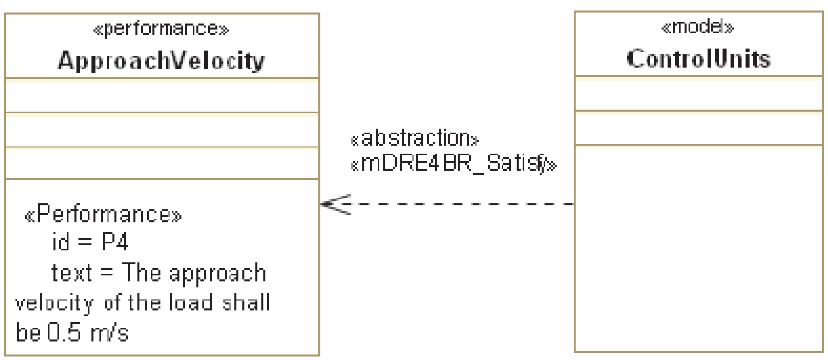
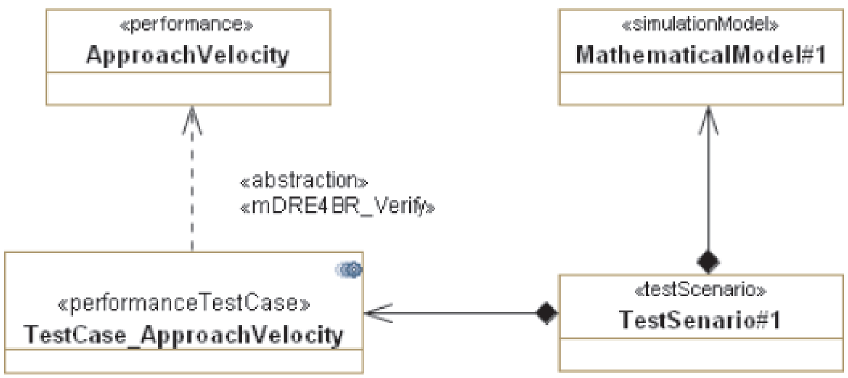
Step 3: Establish Traceability Links

- Satisfy
  - Select the design object supposed to satisfy the requirement
  - Check and update the *Satisfy State*
  - Check the coverage of requirements



- Verify
  - Define test case for each analytically-verifiable requirement
  - Create the verify relation
  - Binding the variables

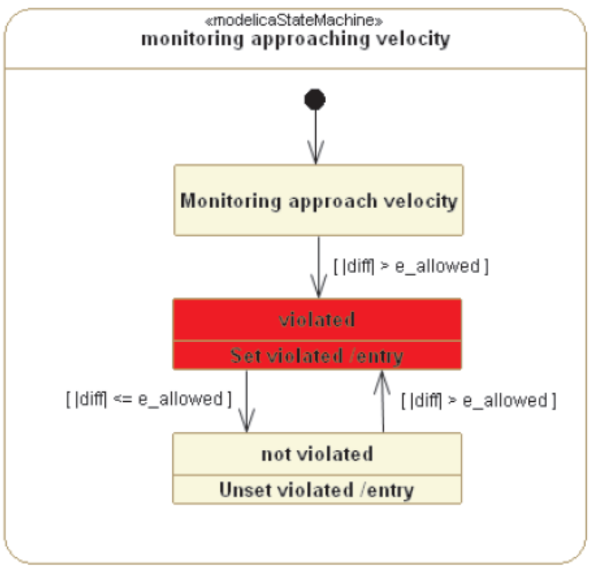


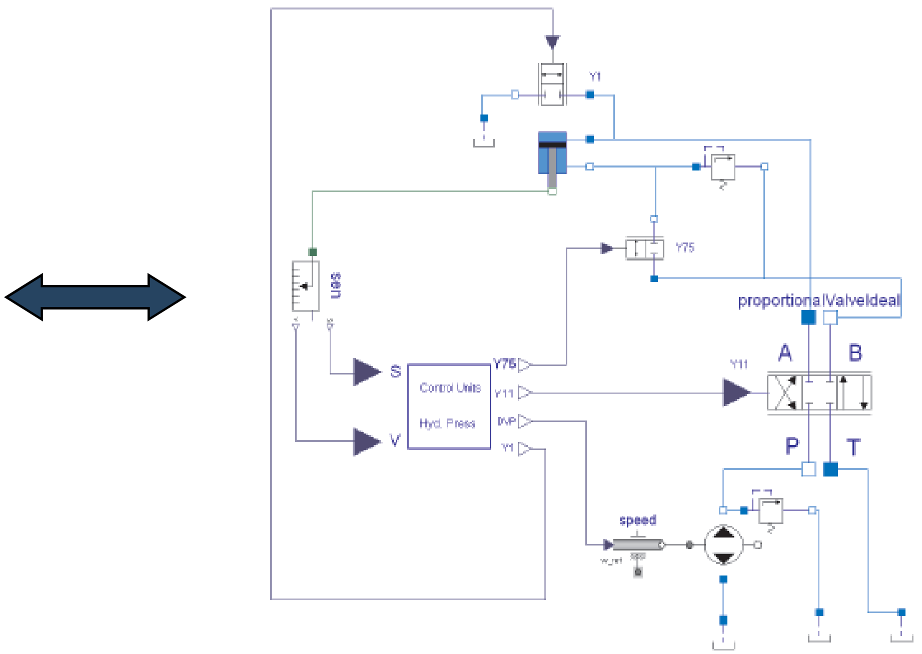
Remarks

- Improved impact analysis by using the extended traceability links

Step 4: Create Analytical Models

- Modeling test case including violation monitor (vVDR, [Schamai, 2010])
- Creating related mathematical models
- Link the mathematical model and test cases in the test scenario





Remarks

- The vVDR method is applicable to our MDRE process

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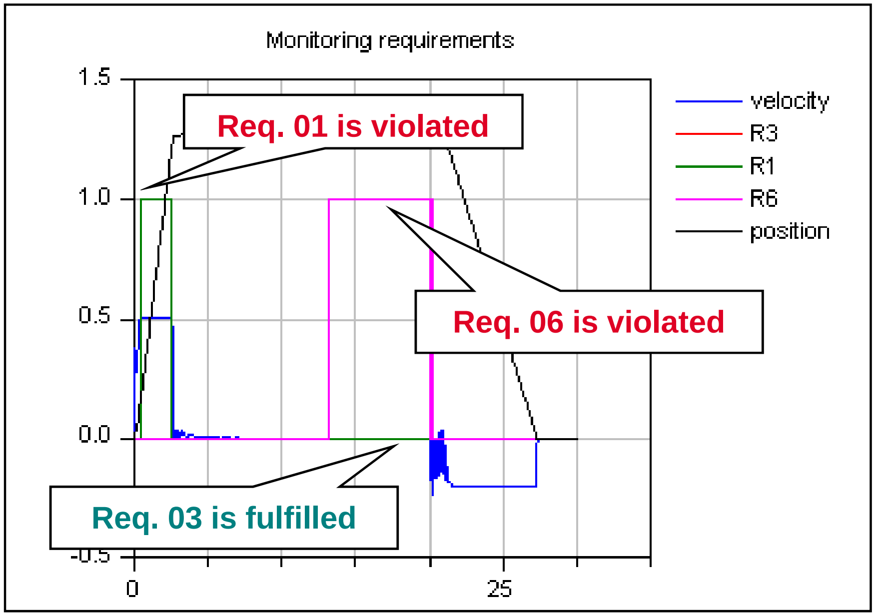
Step 5: Update Results of Verification

- Run the simulation
- Update the *Verify State* in each requirement



ID	Description	?
R1	The approaching velocity of the load shall be 0.5 m/s.	
R2	The maximum force of cylinder can not exceed 200 kN	
R3	The pressing velocity must not exceed 10 mm/s	
R4	The cycle time shall not exceed 27.5 s	
R5	The returning velocity shall be 0.2m/s	
R6	The pressing position shall be 1300 mm, the allowable error is 1mm.	

Remarks

- Automatic update the *Verify State* is desired

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Conclusion and Outlook

Conclusions

- Engineering of industrial automation systems benefits from the MDRE
  - Formal requirements modeling
  - Standard modeling languages covering the whole development process
  - Automatic verification process
- The enhanced SysML requirement constructs of the MDRE4BR profile have been demonstrated by the case study

Outlook

- Finishing the implementation of the Modelica code generator considering traceability links
- Integrated tool support for the whole process

Thanks for your attentions!

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