



## Preparing for the 4.0 Future: Industry strategies in anticipation of 4.0.

1. Introduction of TUM and AIS
2. Cyber Physical Production Systems/Industrie 4.0 – terms and challenges
3. Reconfiguration and data analytics in context of Industrie 4.0
4. Conclusion and Outlook

**Univ.-Prof. Dr.-Ing. Birgit Vogel-Heuser**

Full professor and Director of Institute – Automation and Information Systems (AIS)

Faculty of Mechanical Engineering

Technische Universität München

Member of **EduNet**



# Technische Universität München



- **37,343 students**
- **13 faculties**
- **3 Integrative Research Centers**
- **6 Corporate Research Centers**
- **12,490 female students**
- **9,876 staff members**
- **411 buildings**
- **~ €1.1 billion invested in construction since 2001**

## Students by department

Students by Department	Total	No. of female students	No. of international students
Mechanical Engineering	5,313	760	1,175

## Memberships

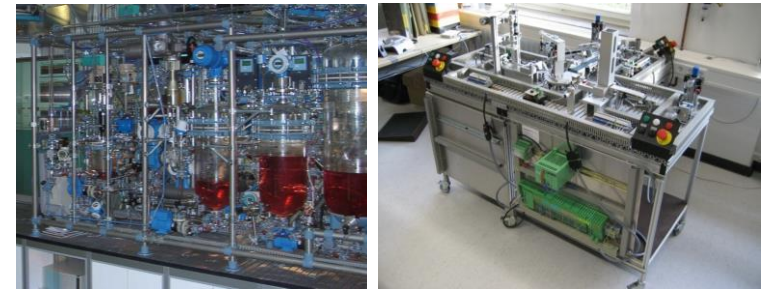
- Chair of VDI/VDE (Association of German Engineers) TC 5.15 “Multi-Agent Systems in Automation”
- Coordinator of CRC (Collaborative Research Center) 768 “Managing cycles in innovation processes”
- Co-Initiator of PP (Priority Programme) 1593 “Design for Future – Managed Software Evolution”

## Scientific staff

- ca. **20** PhD students
- **9** technicians, trainees (software engineering)

## Teaching

- Basics of Information Technology (1st and 2nd Sem., 8 ECTS)
- Modeling and Simulation (5th Sem., 5 ECTS) plus Practical Training (4 ECTS)
- Automation I and II (from 5th Sem., 5 ECTS) plus Practical Training (4 ECTS)
- Industrial Software-Development for Engineers I and II (from 5th Sem., 5 ECTS) plus Practical Training (4 ECTS)
- Development of Intelligent Distributed Embedded Systems in Mechatronics (from 5th Sem., 5 ECTS)







# Overview of the functionality of our e-learning tool PIT



```

13 if(fLaenge>5 || iSitze>7)
14     fPreis*=1.2;
15 else if(fLaenge<4.5 || iSitze<=4)
16     fPreis*=0.8;
17 else
18     fPreis*=0.9;
19
20 printf("Preis: %.2f €\n",fPreis);
21 return 0;
22

```

GESPEICHERT

Speichern   Ausführen   Prüfen   Debug

Continue   Stop   Step in   Step over   Step Return

Variable	Wert
fPreis	1.5
flaenge	2.29999995
iSitze	8
iTest	1

Parameter

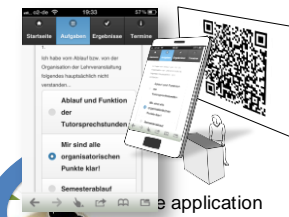
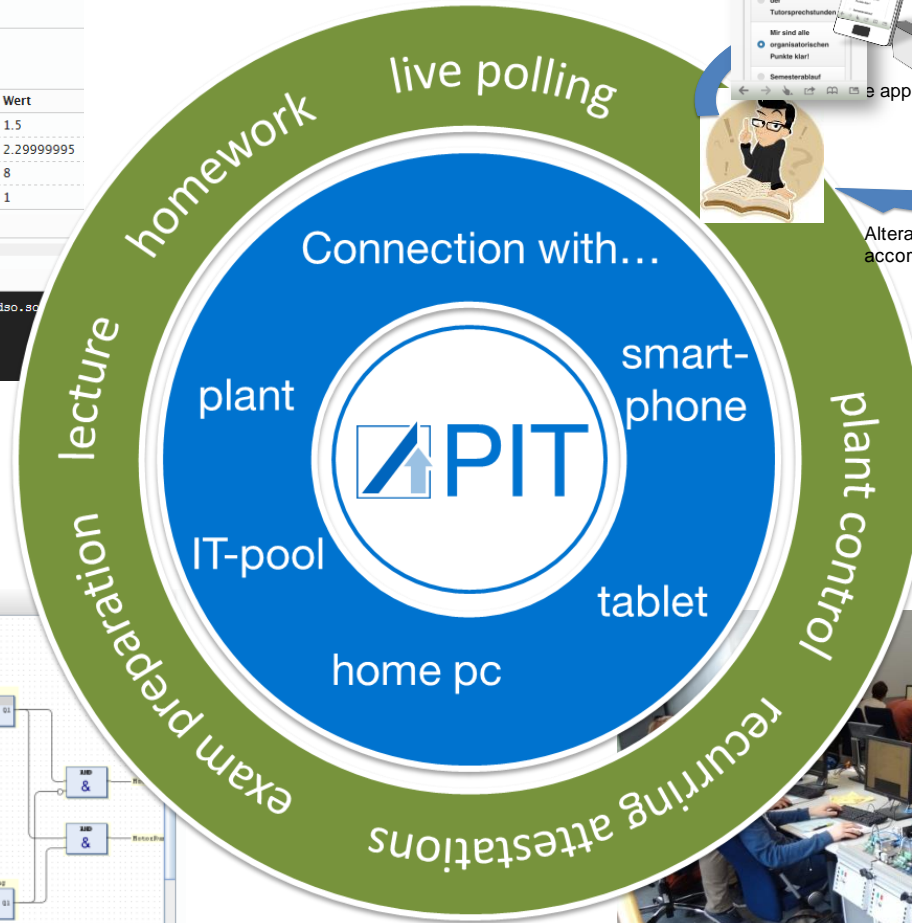
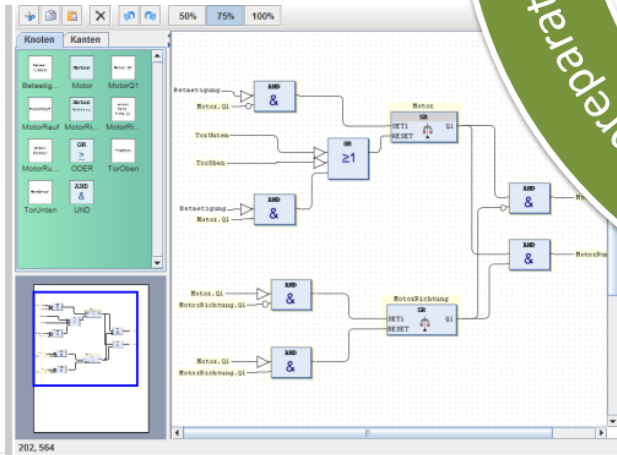
1 2,3  
2 8

Ausgabe ● Debugging-Befehl ausgeführt!

```

warning: Could not load shared library symbols for linux-vdso.so.5
Do you need "set solib-search-path" or "set sysroot"?

```



Automated generation of statistics

Live evaluation

Direct feedback during lecture

Alteration of the next lecture according to the students' demands





# Student's desktop view



Browser address bar: <http://pit-testing.ais.mw.tum.de/aufgaben> AIS PIT

Aufgabenstellung anzeigen

```
6 unsigned int vplcZeit = 0; //Ausführungszeit [ms]
7
8 int schritt = 0;
9
10 int main ()
11 {
12     //Programmcode
13     switch(schritt)
14     {
15     default:
16     case 0:
17         aktoren.umsetzer_abstossen = 1;
18         aktoren.umsetzer_vakuum = 0;
19         aktoren.zylinder_ausschieben = 0;
20
21         if(!sensoren.folgestation_belegt && !sensoren.magazin_leer )
22         {
23             aktoren.umsetzer_folgestation = 1;
24             aktoren.umsetzer_magazin = 0;
25         }
26         else
27         {
28             aktoren.umsetzer_folgestation = 0;
29             aktoren.umsetzer_magazin = 1;
30         }
31
32         if(sensoren.umsetzer_folgestation && !sensoren.magazin_leer )
33         {
34             aktoren.umsetzer_folgestation = 0;
35             aktoren.umsetzer_magazin = 0;
36             schritt = 1;
37         }
38         break;

```

Buttons: Speichern Start Stop

Current I/O values

Variable	Wert
sensoren.zylinder_eingezogen	1
sensoren.zylinder_ausgeschoben	0
sensoren.umsetzer_vakuum	1
sensoren.umsetzer_magazin	0
sensoren.umsetzer_folgestation	0
sensoren.magazin_leer	1
sensoren.folgestation_belegt	0
aktoren.zylinder_ausschieben	0
aktoren.umsetzer_vakuum	1
aktoren.umsetzer_abstossen	1
aktoren.umsetzer_magazin	0
aktoren.umsetzer_folgestation	1
Laufzeit	15972
Schritt	4

Current state of the state machine

PIT Server

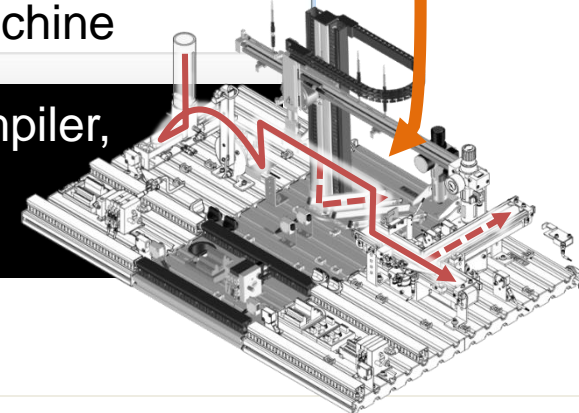


Interface to  
FESTO  
industrial  
plant

Start/Stop functionality to upload the C code in the PIT PLC

Keine Ausgabe (Prüfen)

Results of the C compiler, if compilation fails

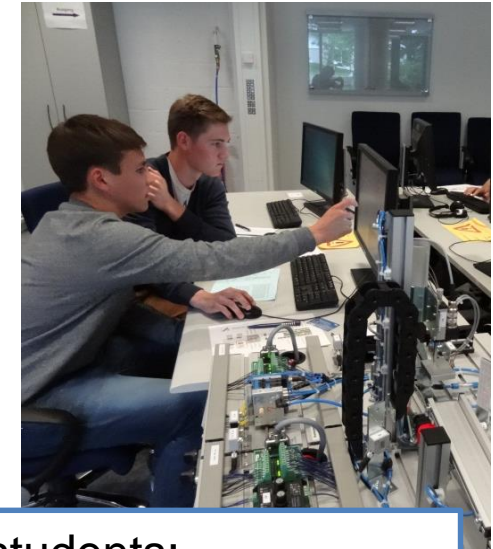
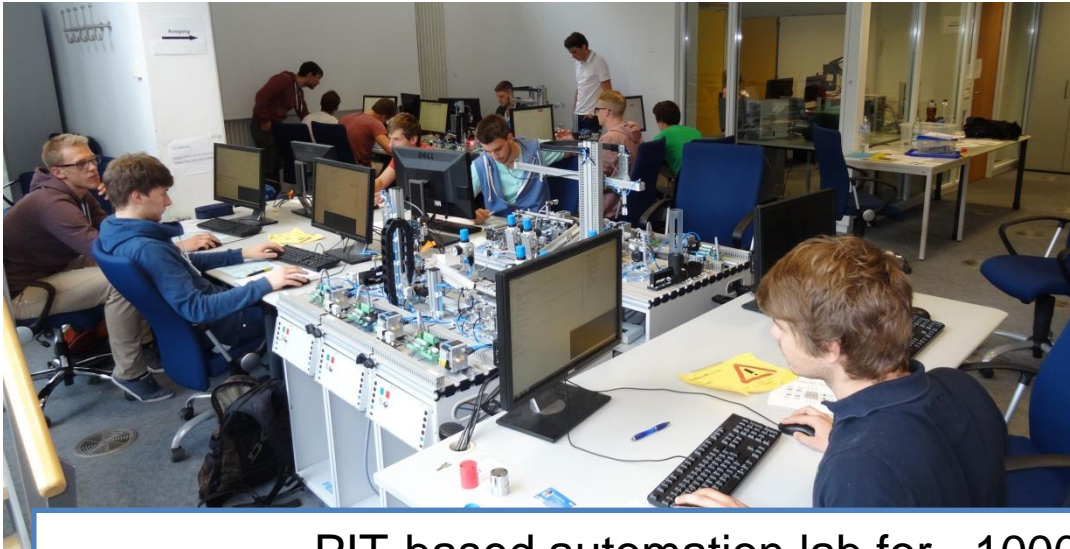


© AIS, 2015





## 2nd semester C-programming lab (mandatory)



PIT-based automation lab for ~1000 B.Sc. students:  
programming of production plants – software engineering on a real  
mechatronic system with actuators and sensors





Since introduction in 2010: **>5200** attendees at PIT

**30.000** presence attestations in PIT with fully automated evaluation

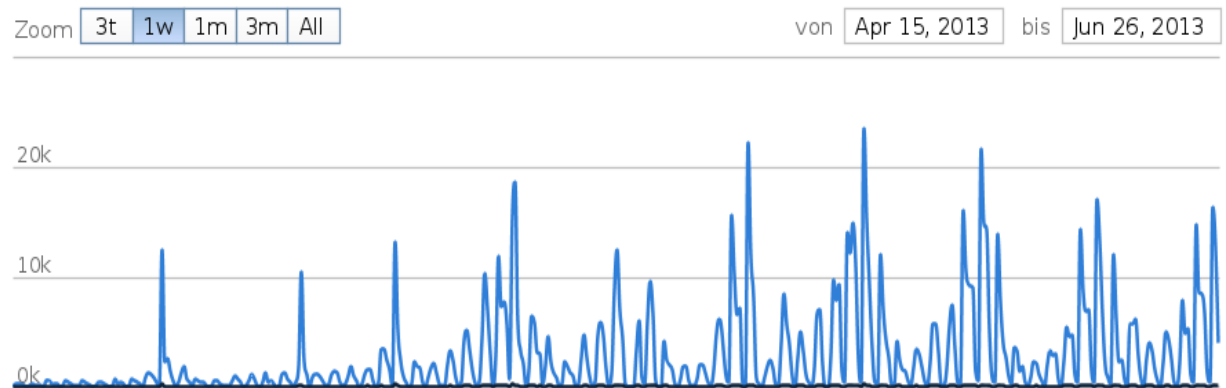
In every summer term:

**2970** plant operation hours with PIT control

**29.000** successful plant launches

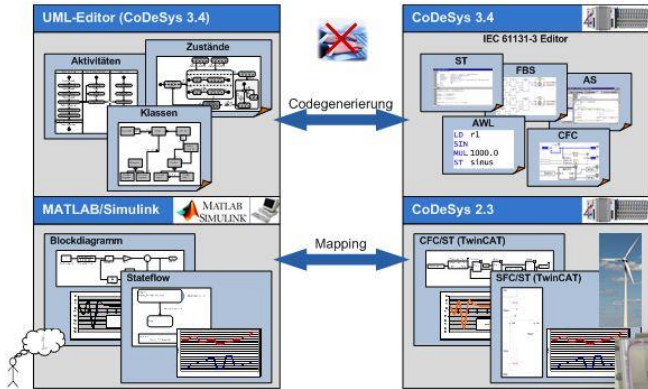
**235.000** C programs compiled successfully (about 250 per student)

up to **25.000** clicks  
in a 6 hour time frame

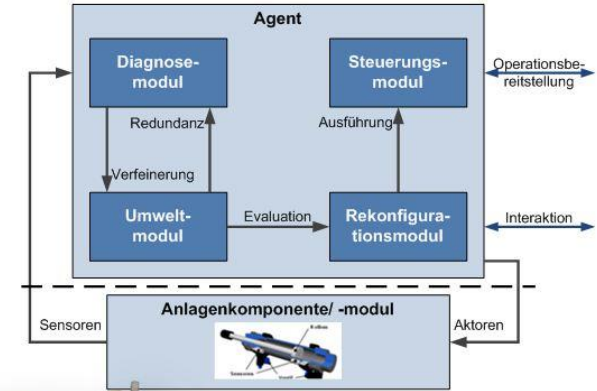


We would be happy to share our experience!

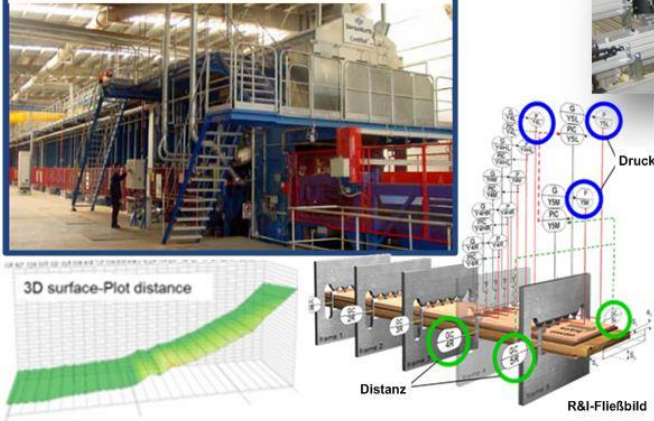
## Model-Driven Development



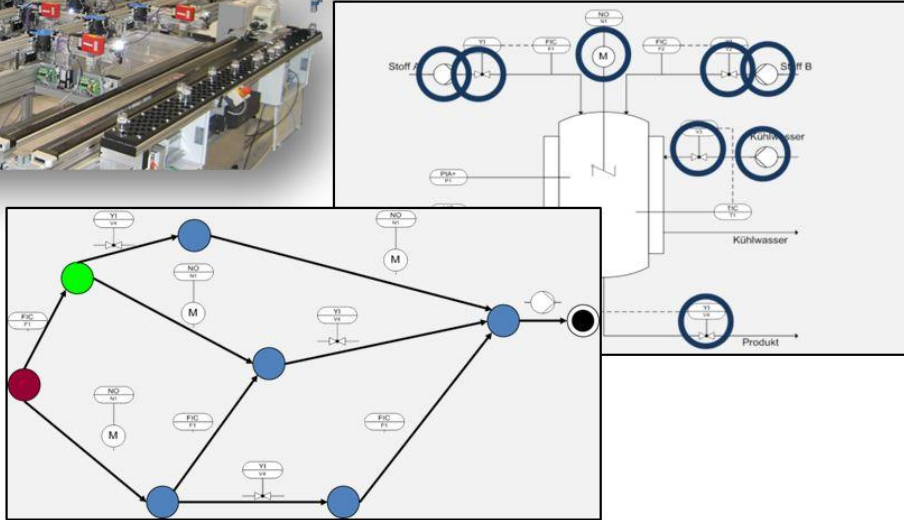
## Intelligent Distributed Systems



### Kontinuierliche thermo-hydraulische Presse in der Holzindustrie



## Smart Information

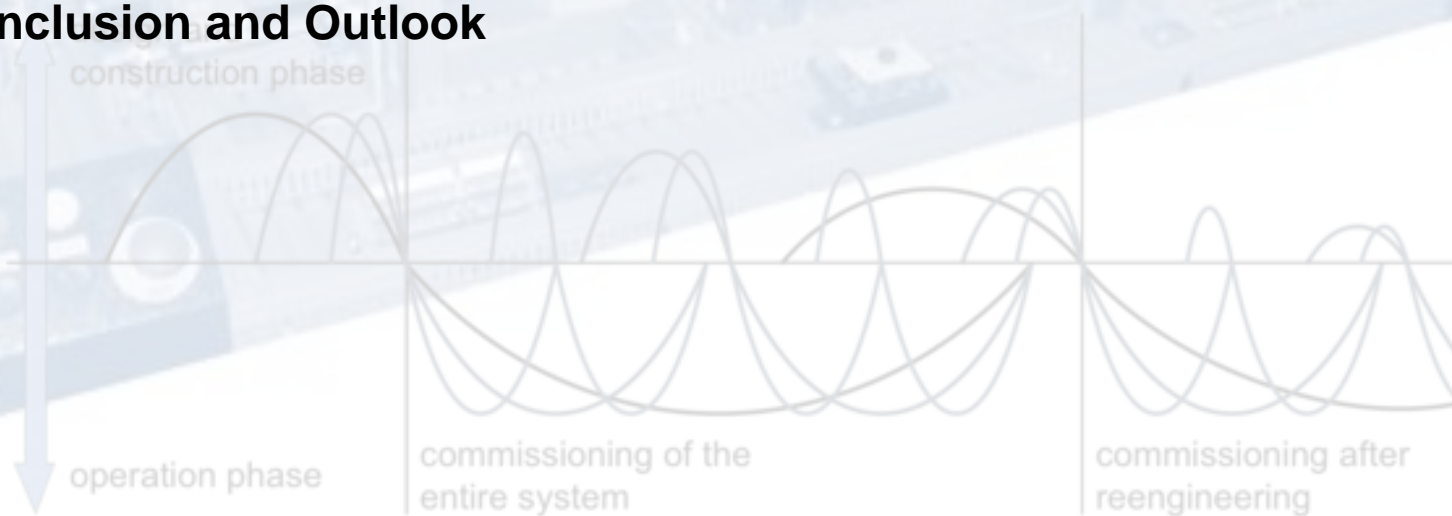


## Big Data in aPS



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Assistance systems for Engineering

Data processing and integration for humans



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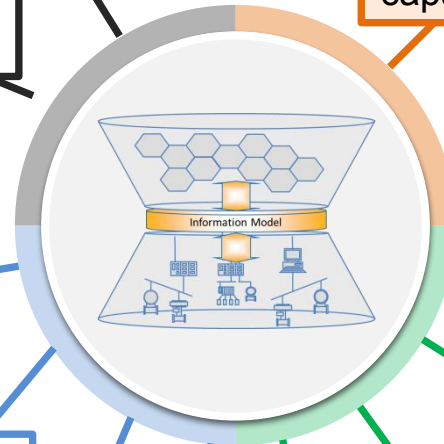
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**World wide distribution of data, high availability, access protection**

**Data consistency** about different „stakeholders“ in different engineering phases and crafts

**Digital networks** and interfaces for communication (between machine, human and plant, plant and plant)

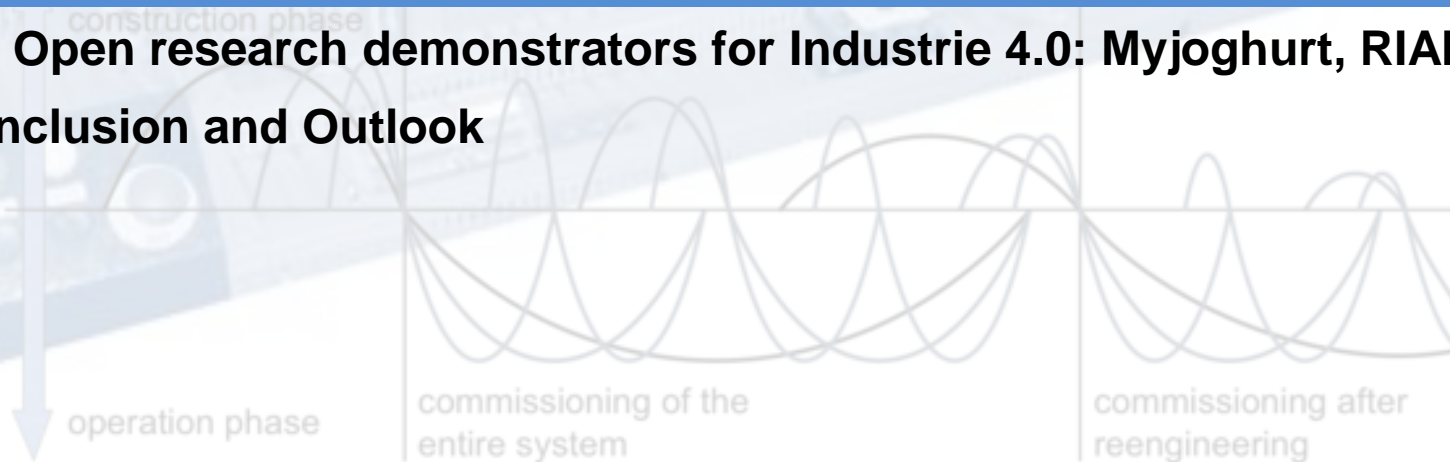


Source: B. Vogel-Heuser, G. Bayrak, U. Frank: Forschungsfragen in "Produktautomatisierung der Zukunft". acatech Materialien. 2012.



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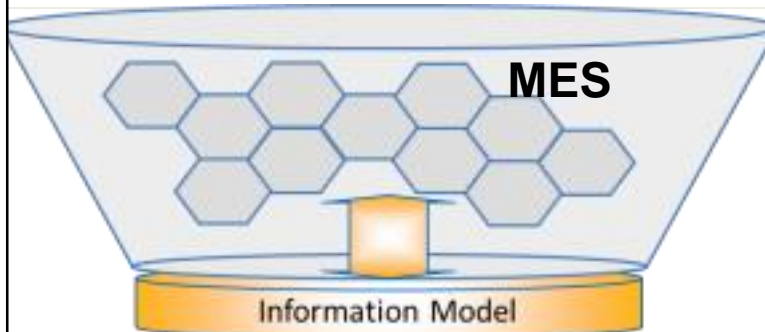


# Industrie 4.0 Interface for Machines and Plants



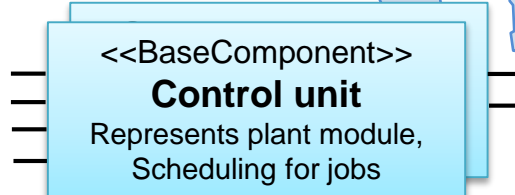
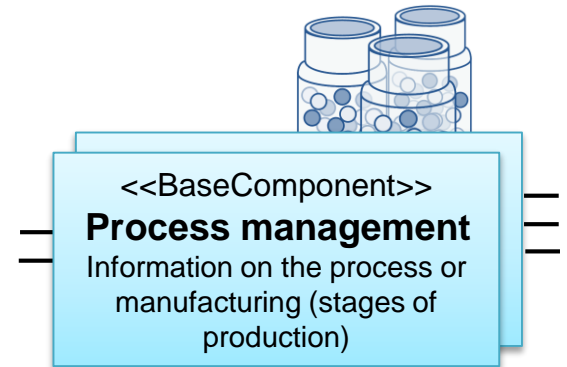
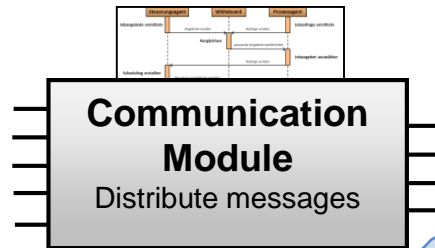
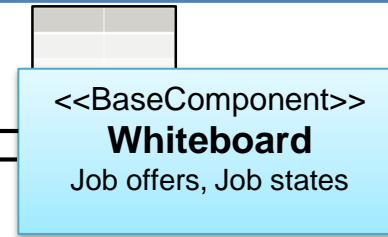
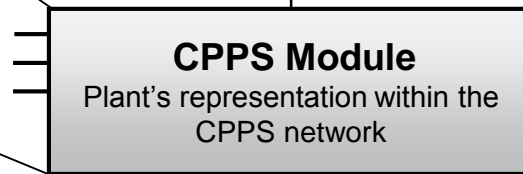
Description of the machine and its configuration:

- abilities (operations)
- units' status (e.g. OMAC/PackML)
- relevant data points e.g. for tracking/tracing



- Process steps (recipe)
- parameters

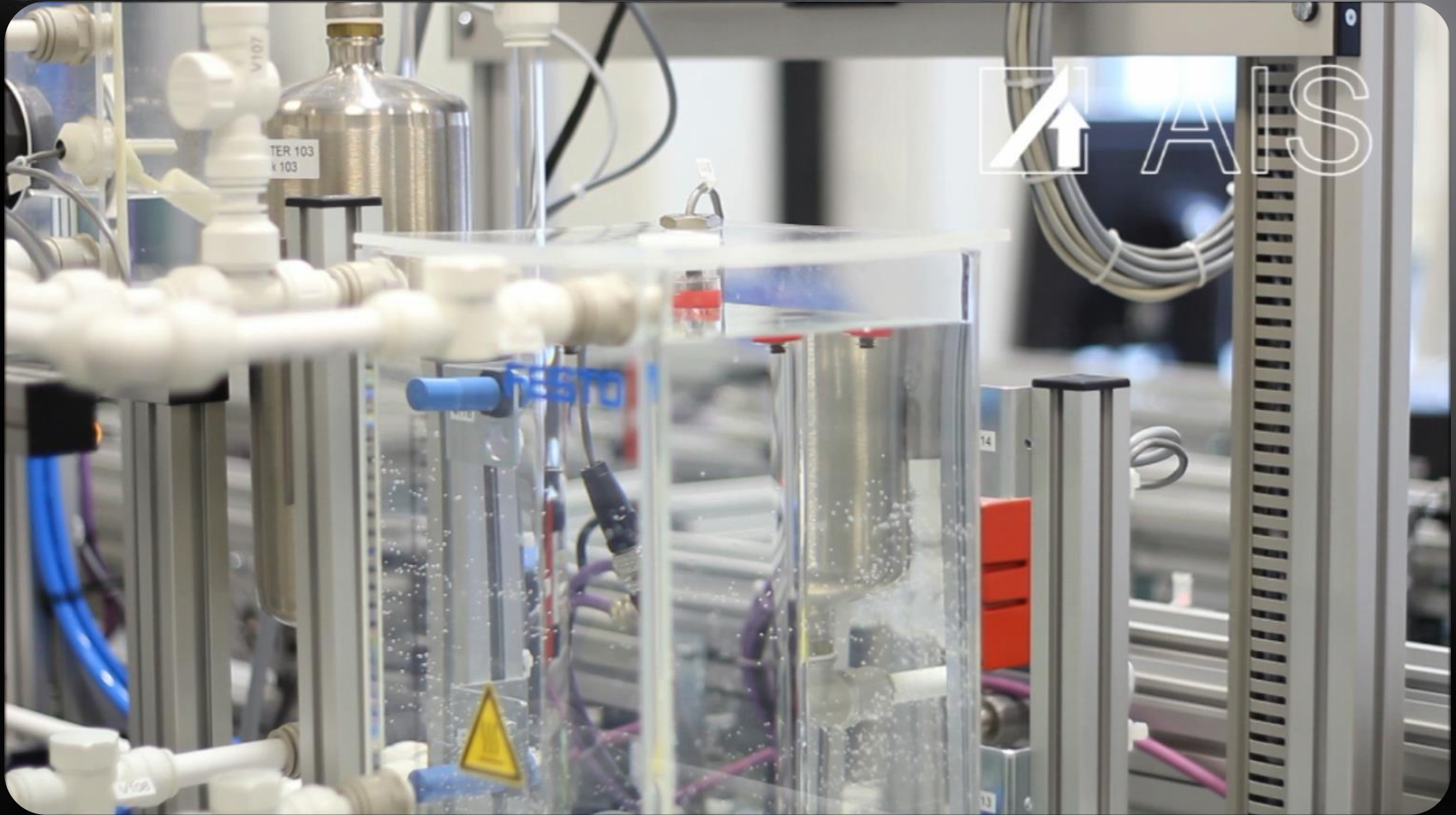
14.0 Interface (TCP/IP)



**IEC 61131-3 control program**



# Motivation for agents on field level



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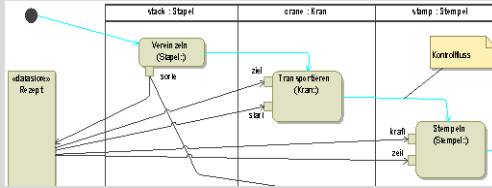


# KREAagentuse: SysML-based automation software development

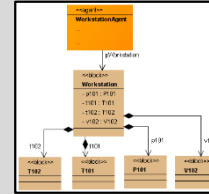


Tool-Supported Development  
of Agents' Knowledge-base

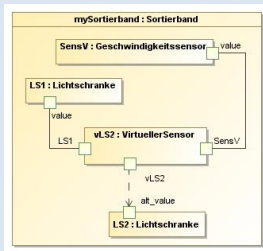
## AD: Technical Process



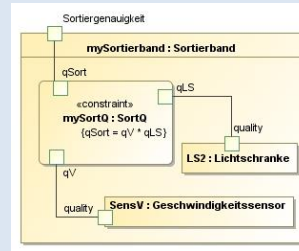
## BDD: Software Structure



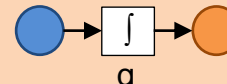
## PD: Redundancy Model



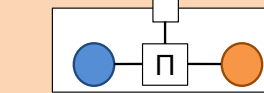
## PD: Tolerance Model



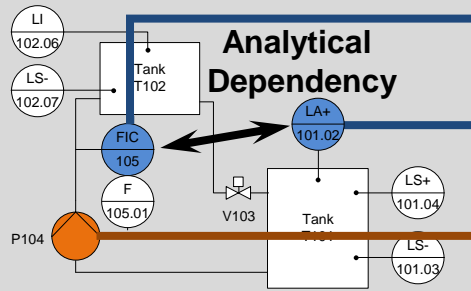
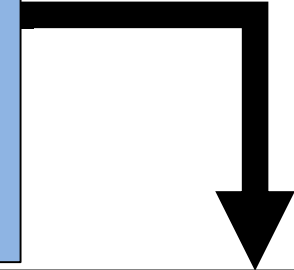
## Agent Models Redundancy Model



q



Model Transformation/  
Code Generation



Production Plant

Self-Aware  
Sensor Agent



Main Routine

Real-Time Capable Fault Tolerant Software

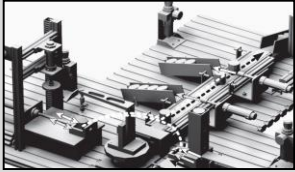
Source: Frank et al. 2011, Schütz et al. 2012, DFG funded project KREAagentuse





# Evaluation: Sensor failure

## Demonstrators



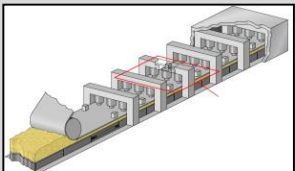
Sorting plant



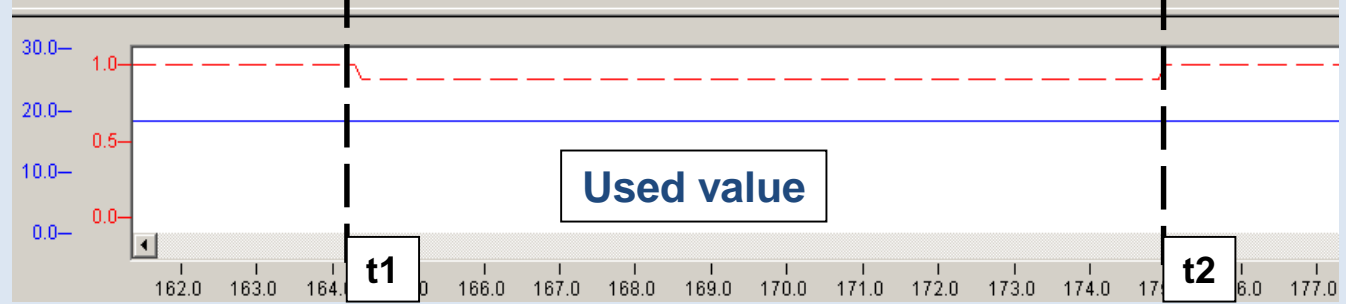
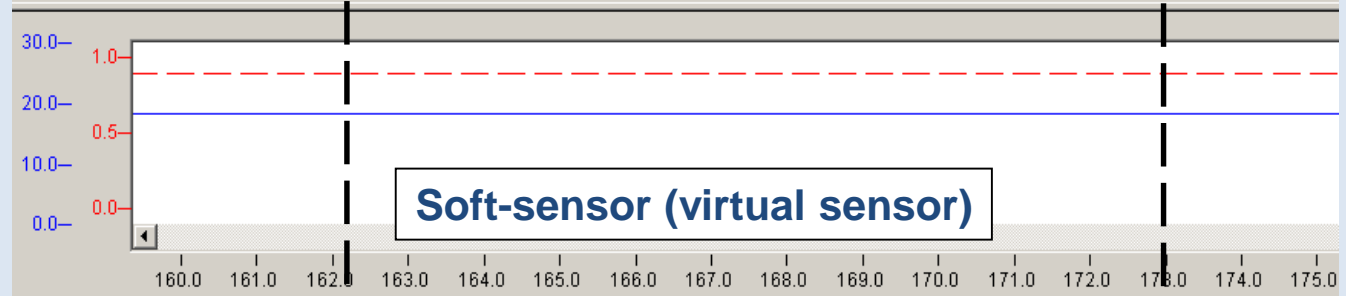
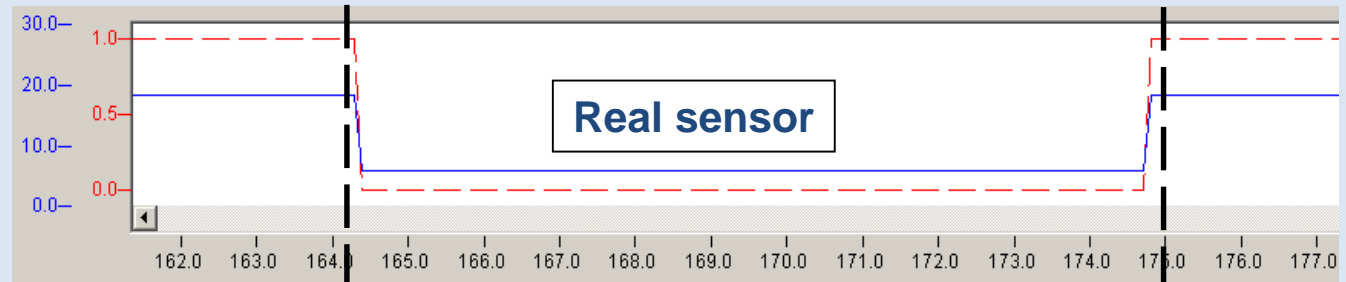
Cognitive factory



Hybrid Process Laboratory Plant



Heating press



Sensor value  $\longrightarrow$  Quality  $\dashrightarrow$

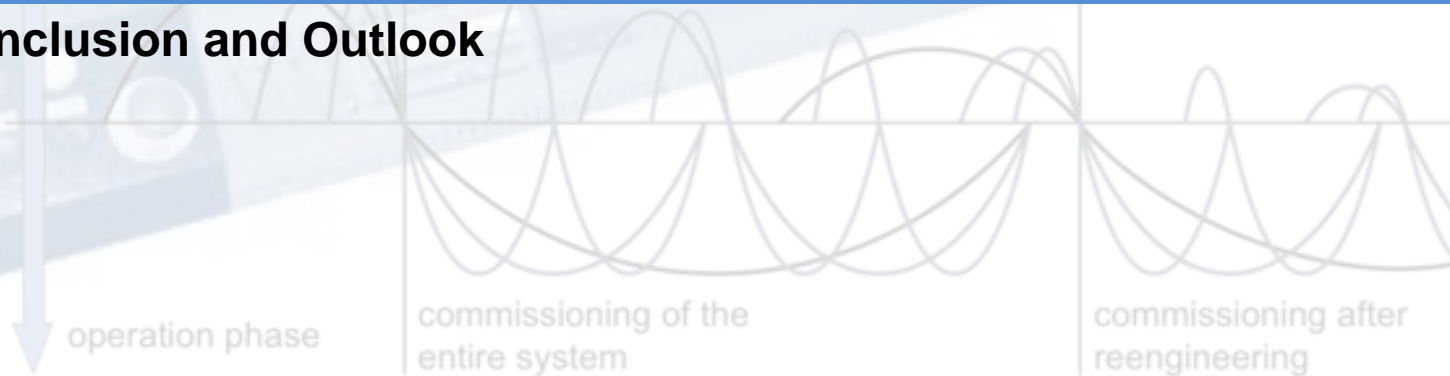
[Wannagat 2010]

**$\longrightarrow$  Sensor failure does not disrupt production process**



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# Characteristics of Cyber-Physical Production Systems (CPPS) - Industrie 4.0



## Data processing for humans

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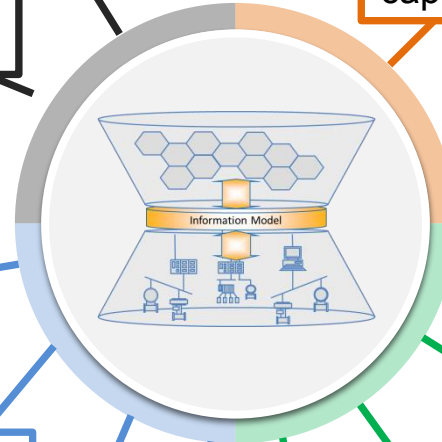
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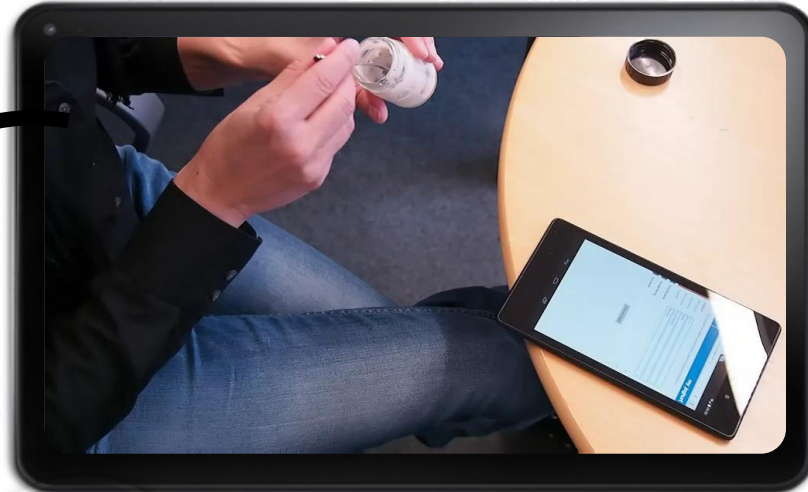
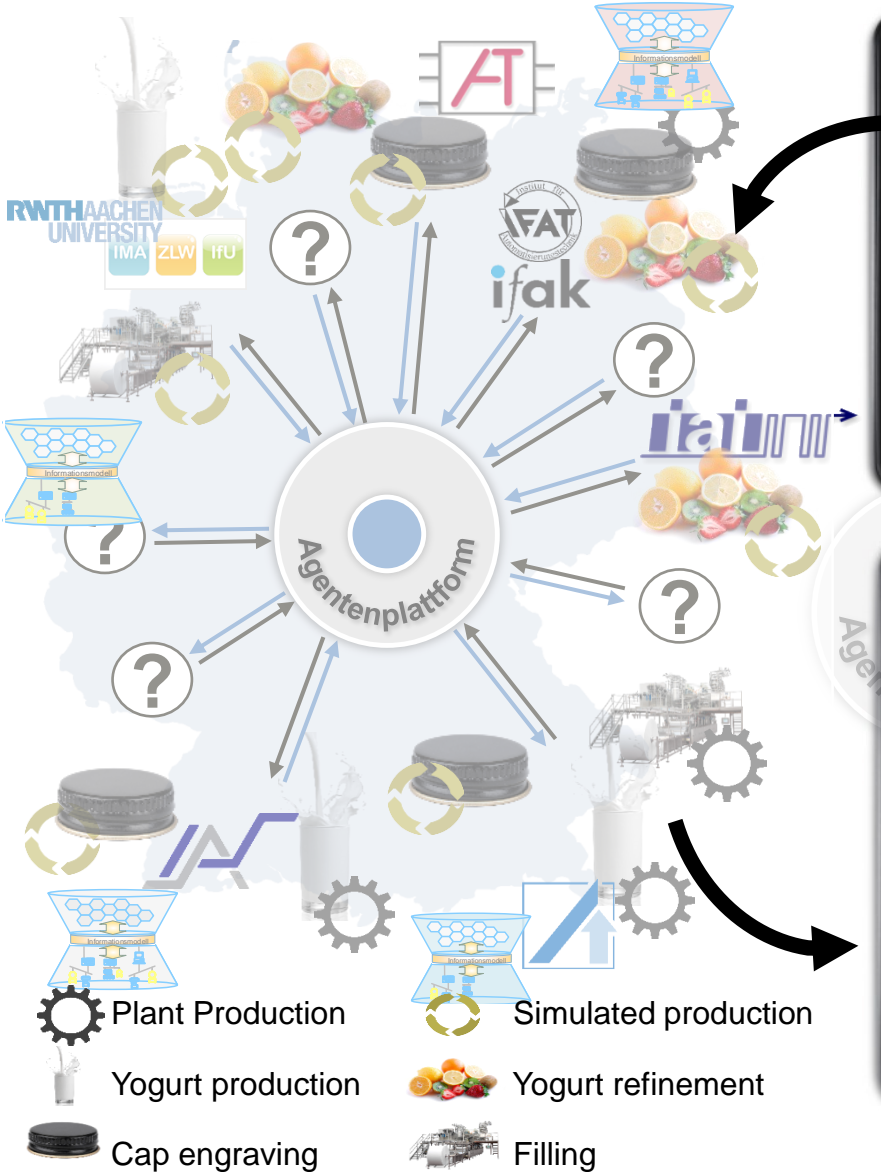


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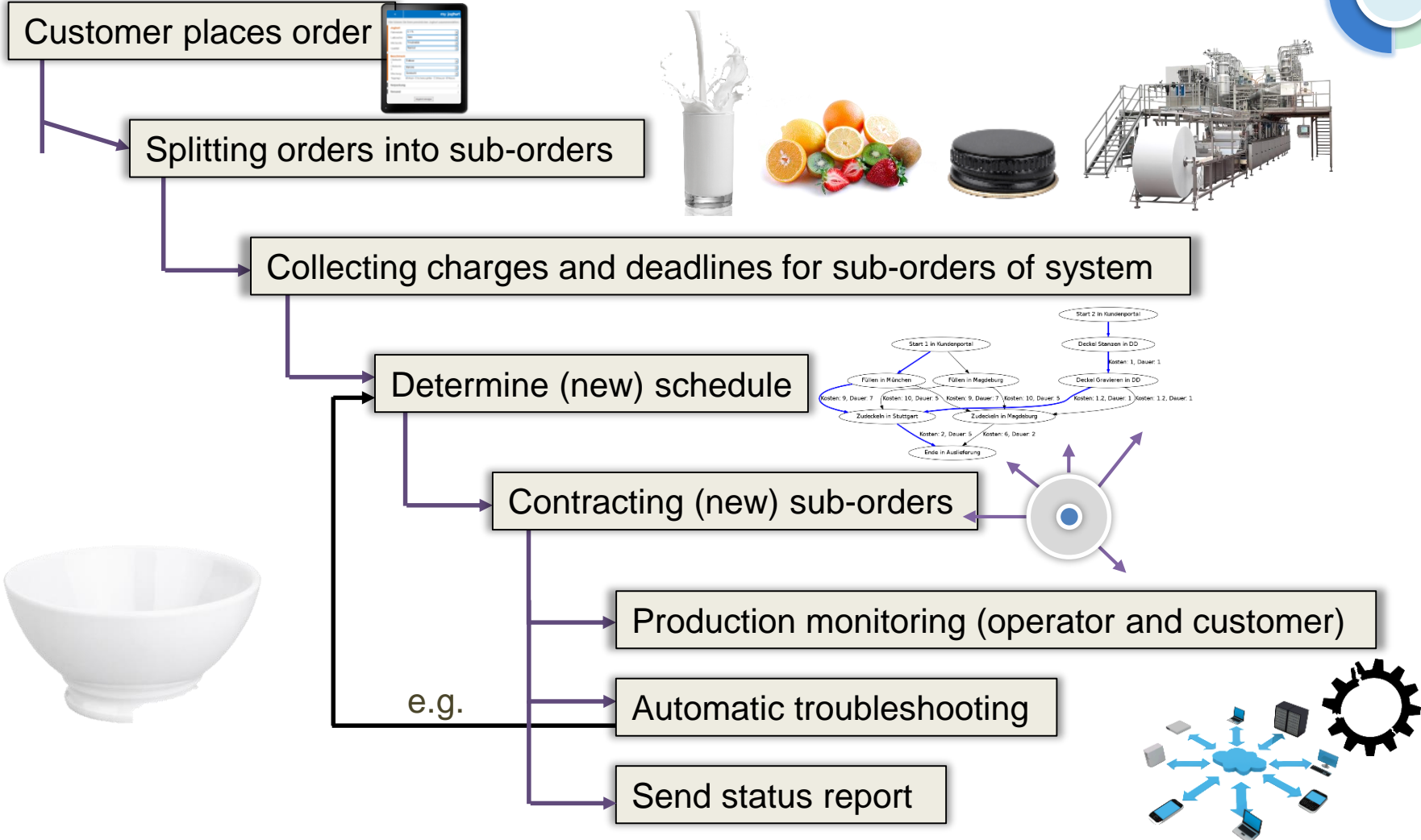
# Intelligent networked production systems – myJogurt how it all began



Website: <http://www.ais.mw.tum.de/myjoghurt/>

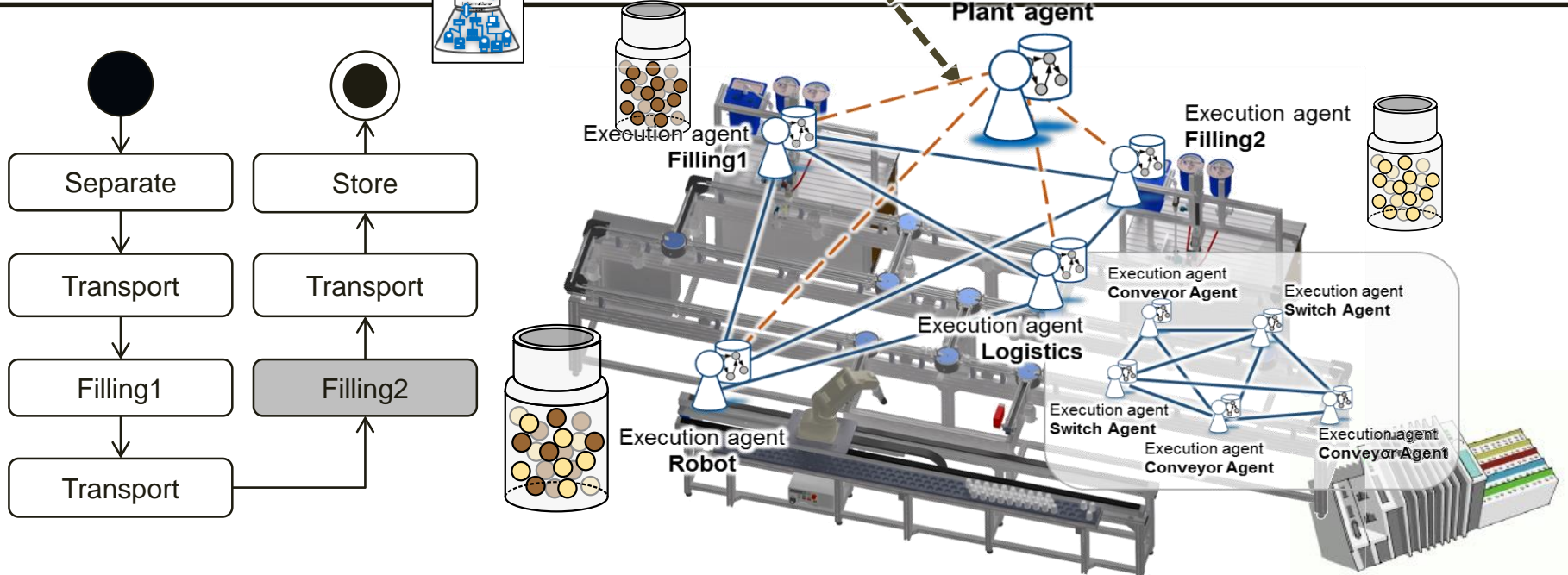
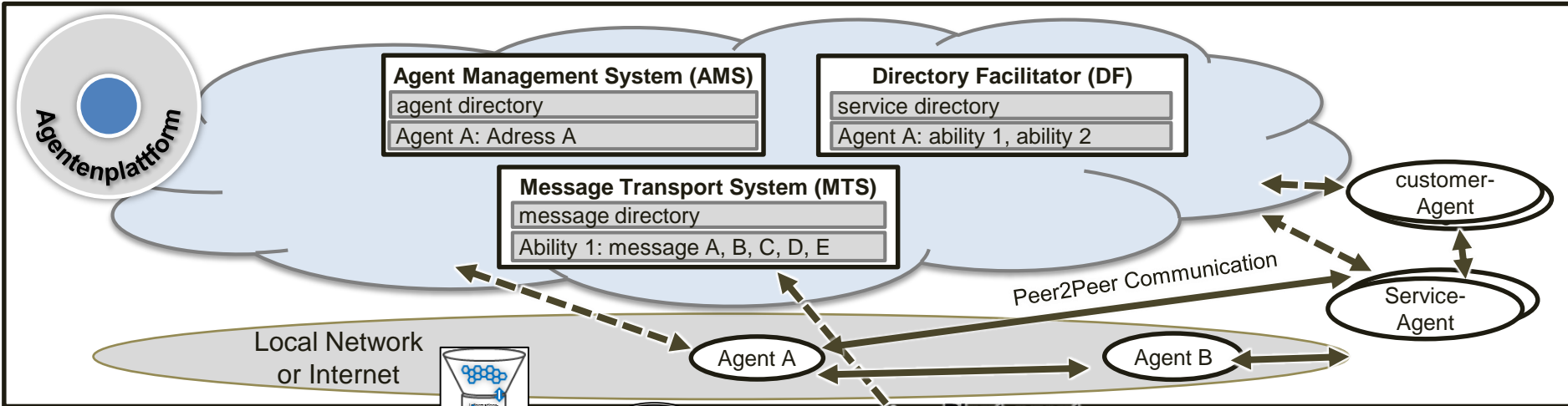


# Procedure of production control

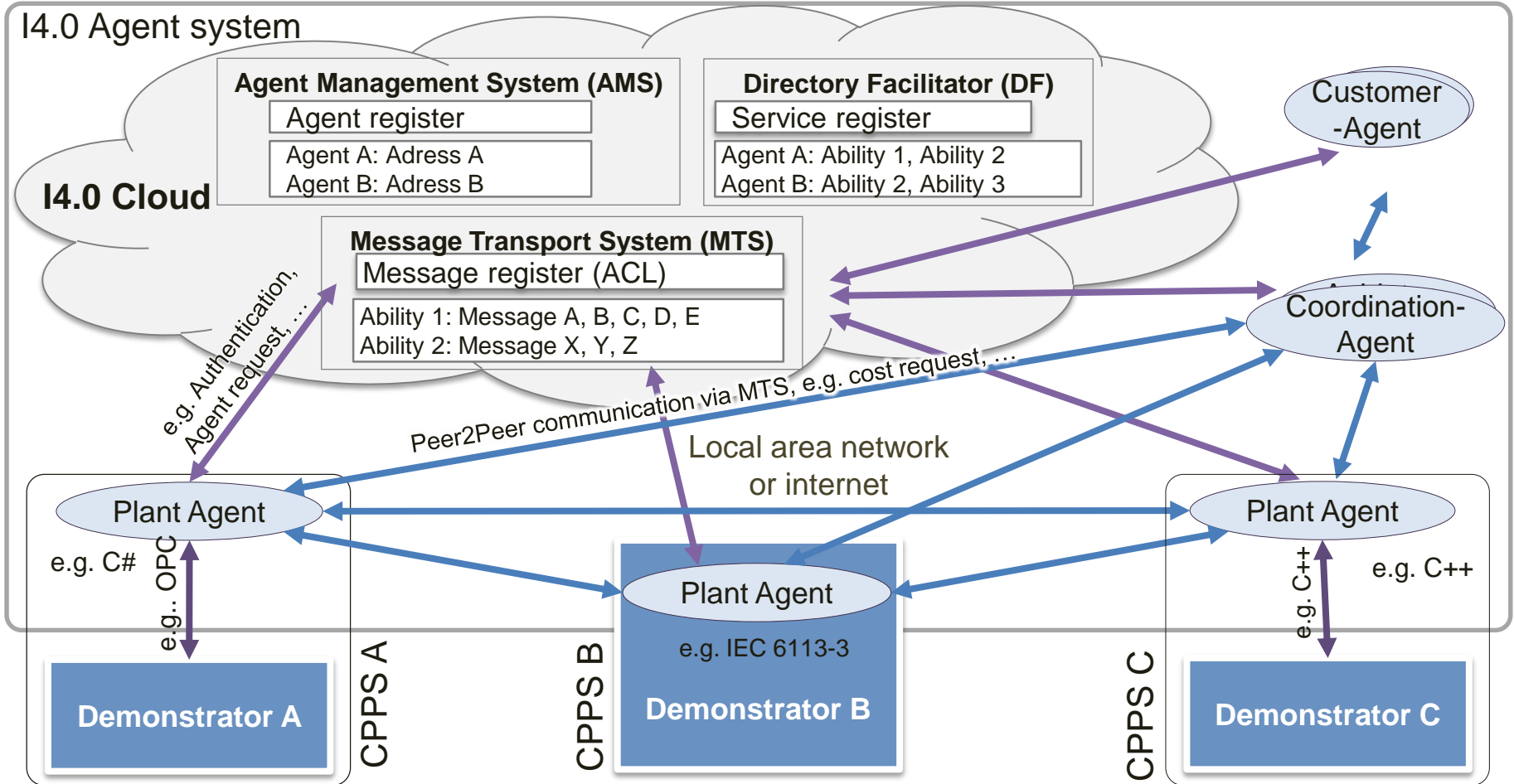




# Self-adaptation of an automated production system



Source: B. Vogel-Heuser: Herausforderungen und Anforderungen aus Sicht der IT und der Automatisierungstechnik. In: Industrie 4.0 in Produktion, Automatisierung und Logistik, Springer, 2014.



Source: D. Pantförder, F. Mayer, C. Diedrich, P. Göhner, M. Weyrich, B. Vogel-Heuser: Agentenbasierte dynamische Rekonfiguration von vernetzten intelligenten Produktionsanlagen – Evolution statt Revolution. In: Industrie 4.0 in Produktion, Automatisierung und Logistik, Springer, 2014.





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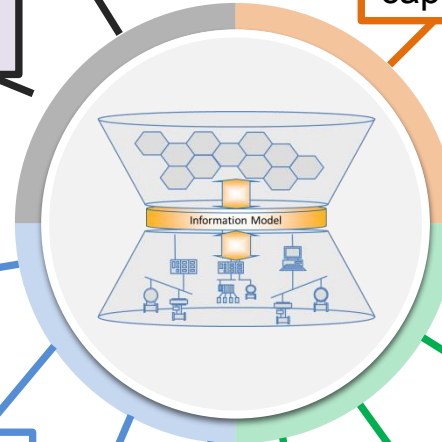
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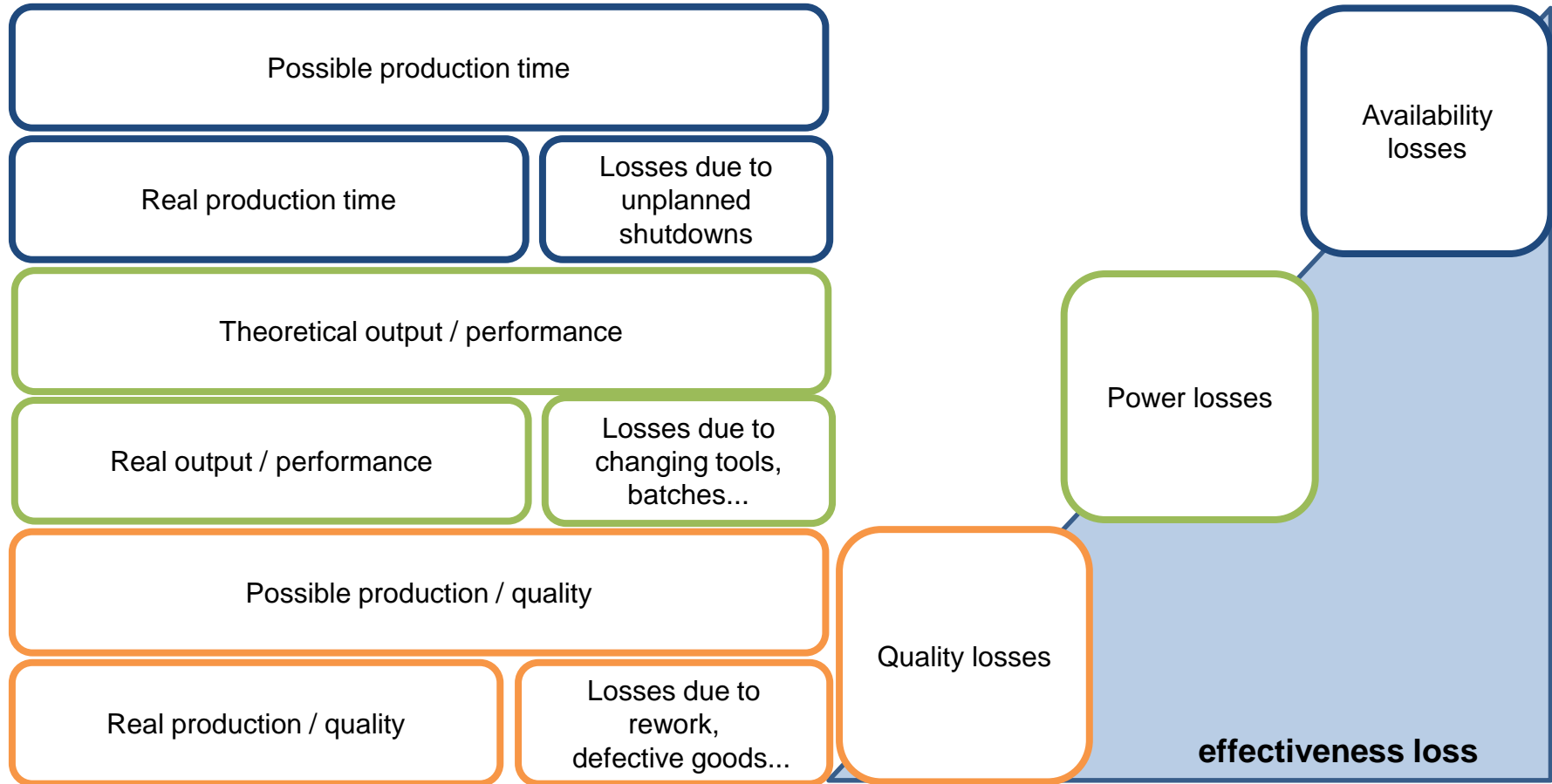
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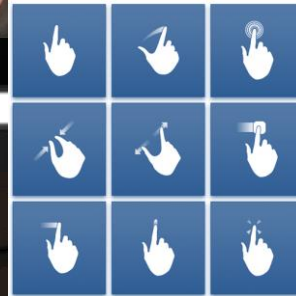
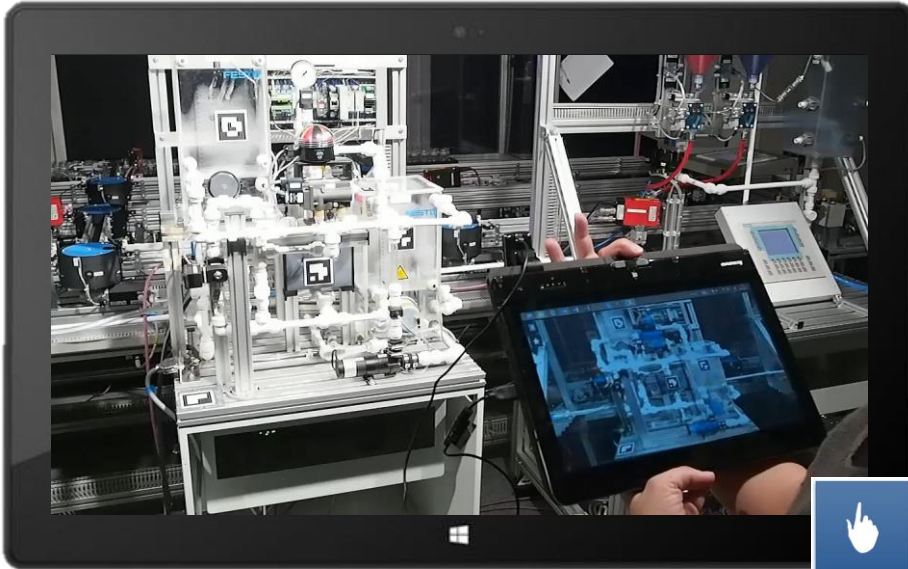


# Overall Equipment Effectiveness (OEE)

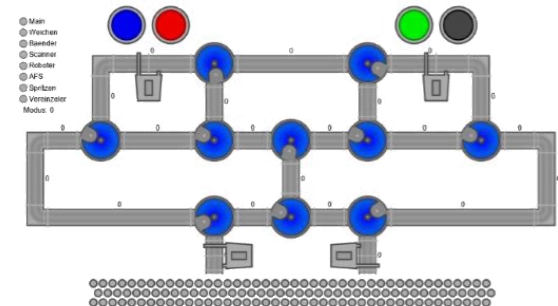
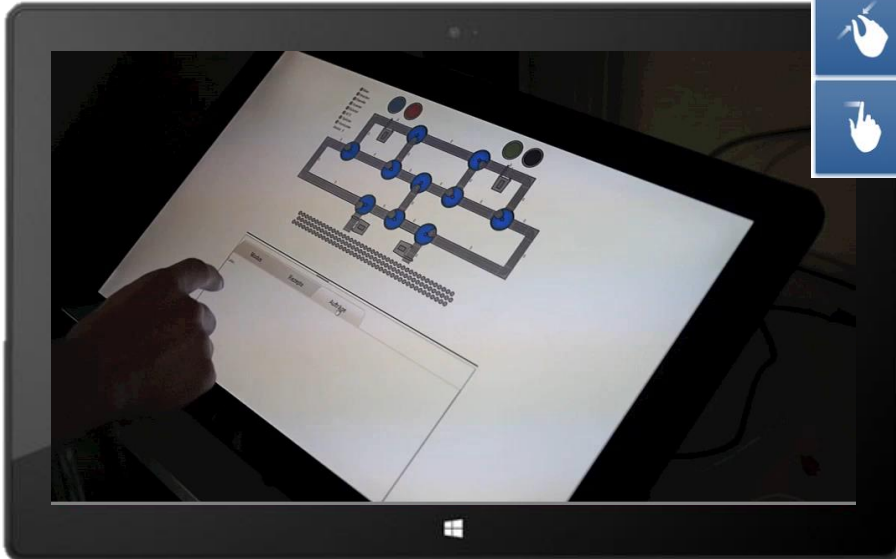




# Scenario: Information aggregation for maintenance HMI with AR and touchscreen



- Mobile devices with touchscreen
- Augmented Reality supports optimization and maintenance of industrial plants





# Information aggregation for maintenance (1)



role  
shift supervisor

shift supervisor undertakes  
role of mechanic

shift supervisor undertakes  
role of operator

## shift supervisor

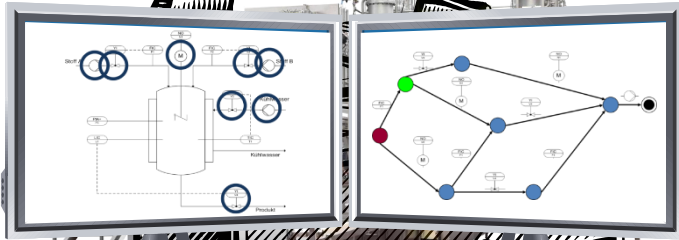


- Red-green color blindness
- Preferred voice control

## role

- shift supervisor
- mechanic
- operator

## Context



Source: Lehrstuhl für Automatisierung und Informationssysteme, TU München





role  
shift supervisor

shift supervisor undertakes  
role of mechanic

shift supervisor undertakes  
role of operator

## shift supervisor

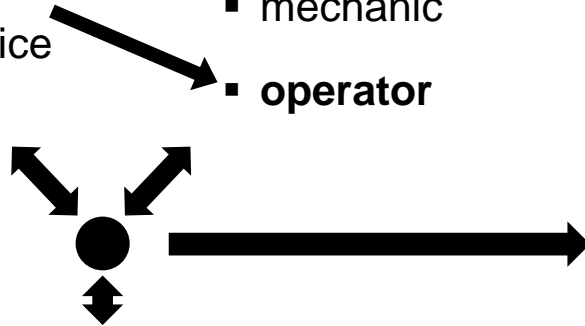
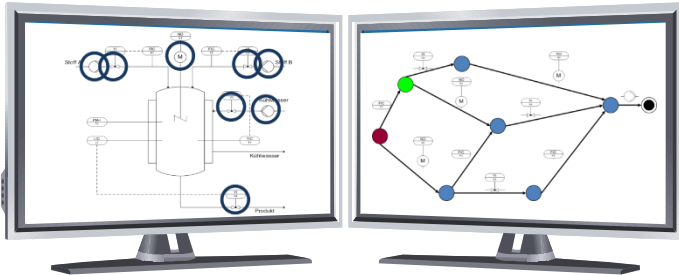


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## role

- shift supervisor
- mechanic
- **operator**

## Context

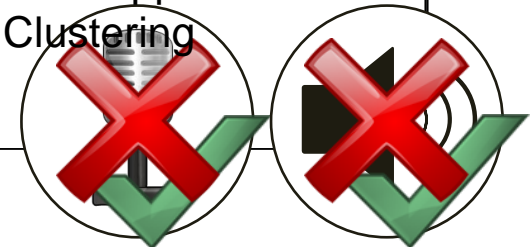


## **challenge**

- Prediction of critical situations based on analysis of process data and alarm sequences
- recommendations for operator

## **approach**

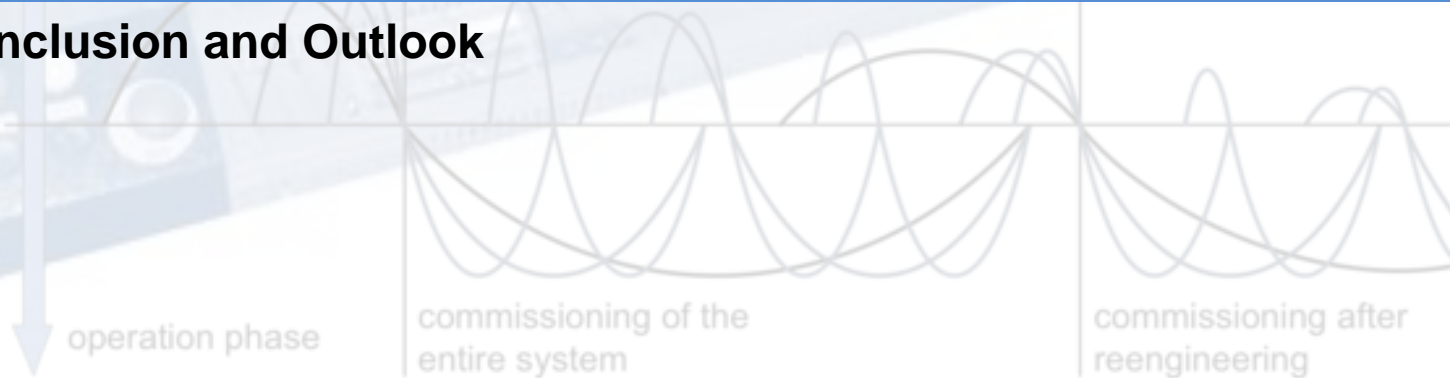
- Pattern analysis, statistical approaches and Clustering





## Preparing for the 4.0 Future: Industry strategies in anticipation of 4.0.

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# Robot Integrated Agent Network (RIAN)



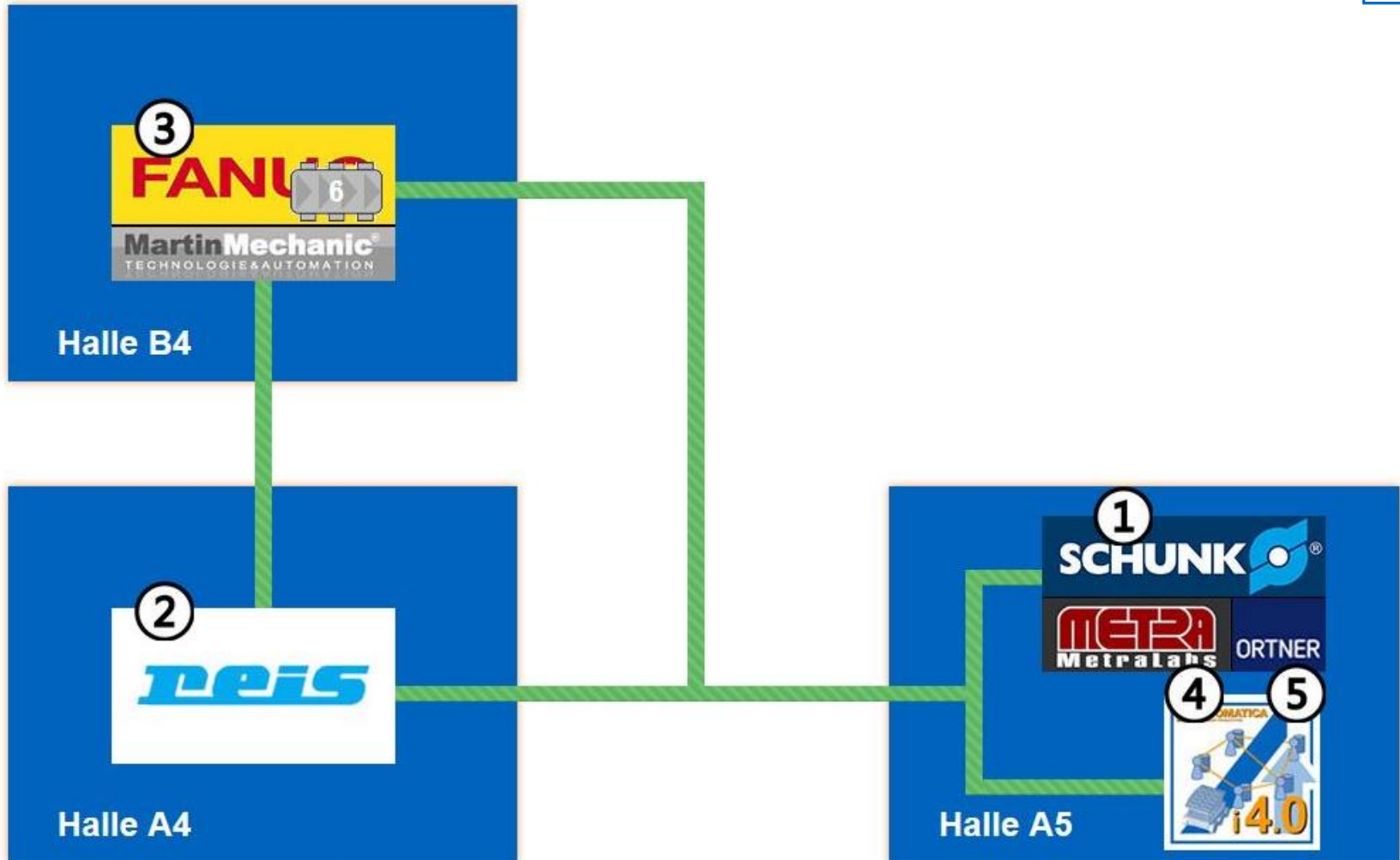
① Storage

② Laser simulation

③ Injection molding

④ Engraving-laser

⑤ Packaging

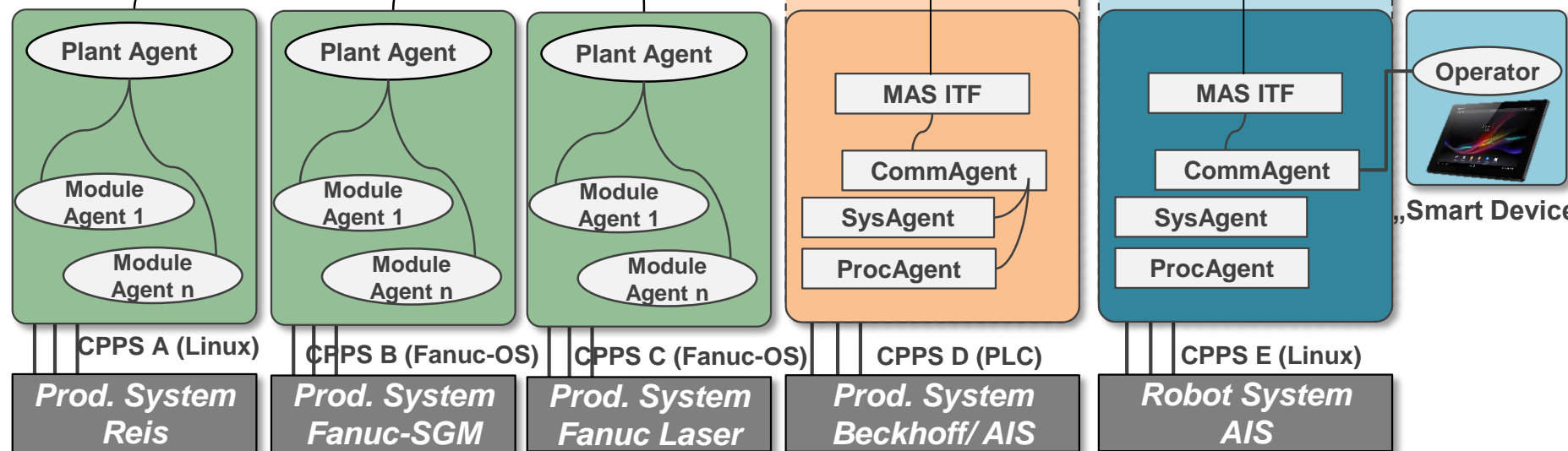
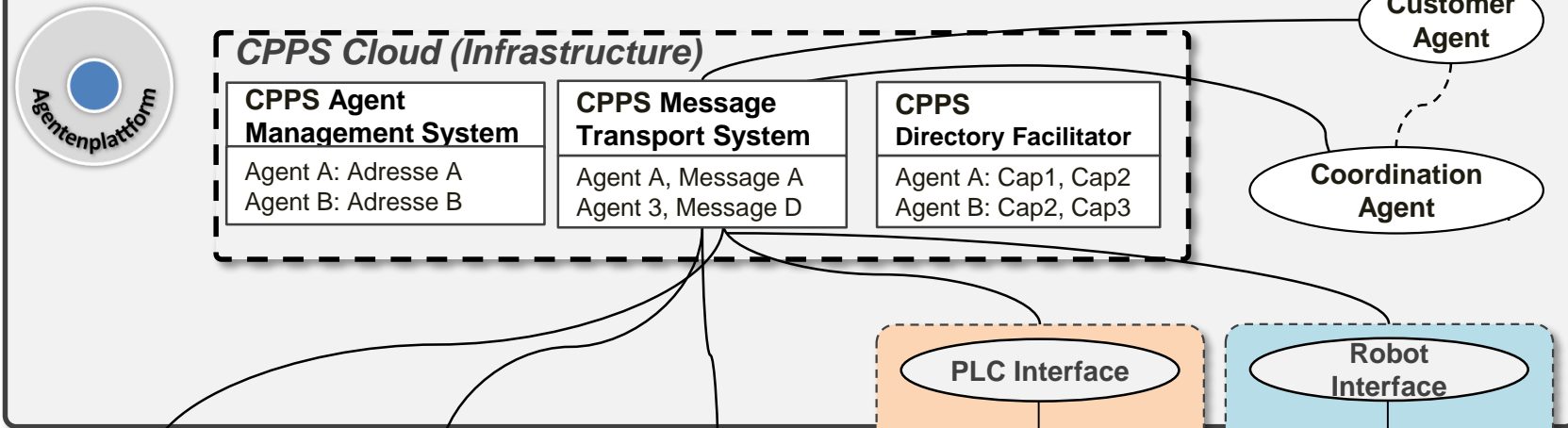




# CPPS architecture based on multi agent system



## CPPS Compound (Multi-Agent System)







# Lessons Learned – Industry 4.0- agent-based migration

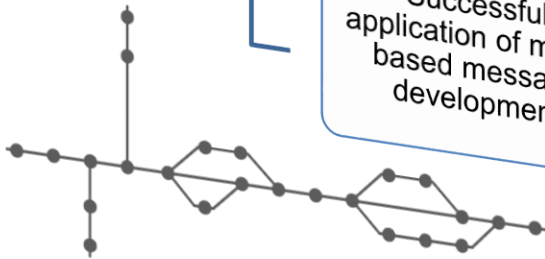


## Definition of messages between agents

Detailed process description necessary

Iterative proceeding necessary

Successful application of model based message development



## Implementation

Connection between heterogenous platforms could be instantiated by agent system

High importance of infrastructure/ restrictions of the network

Detailed planning of integration

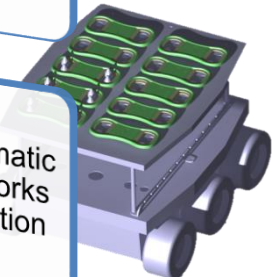


## Mobile transport robots

Separation into realtime and non-realtime communication

Low data load facilitates fast data exchange via the Internet

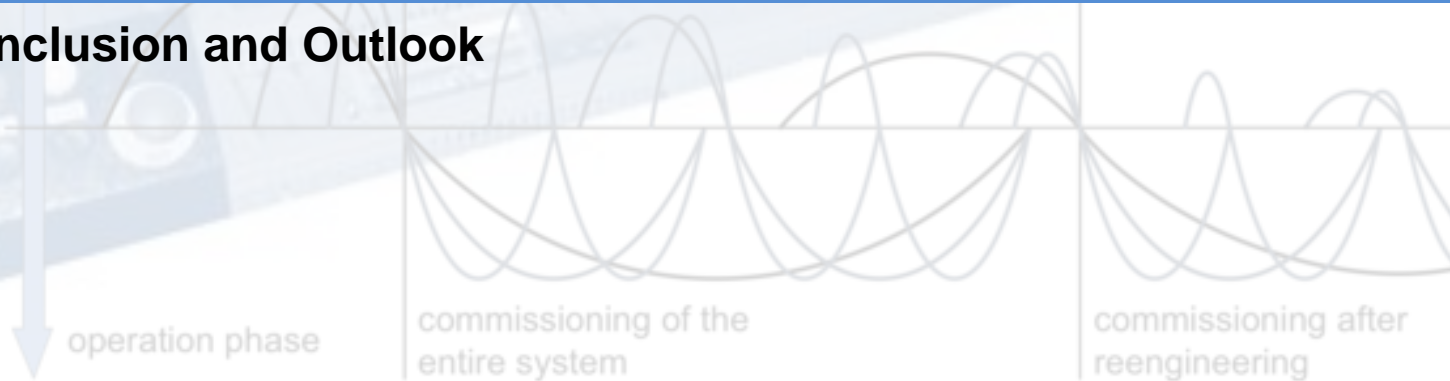
Provide for automatic dialing into networks and reconfiguration

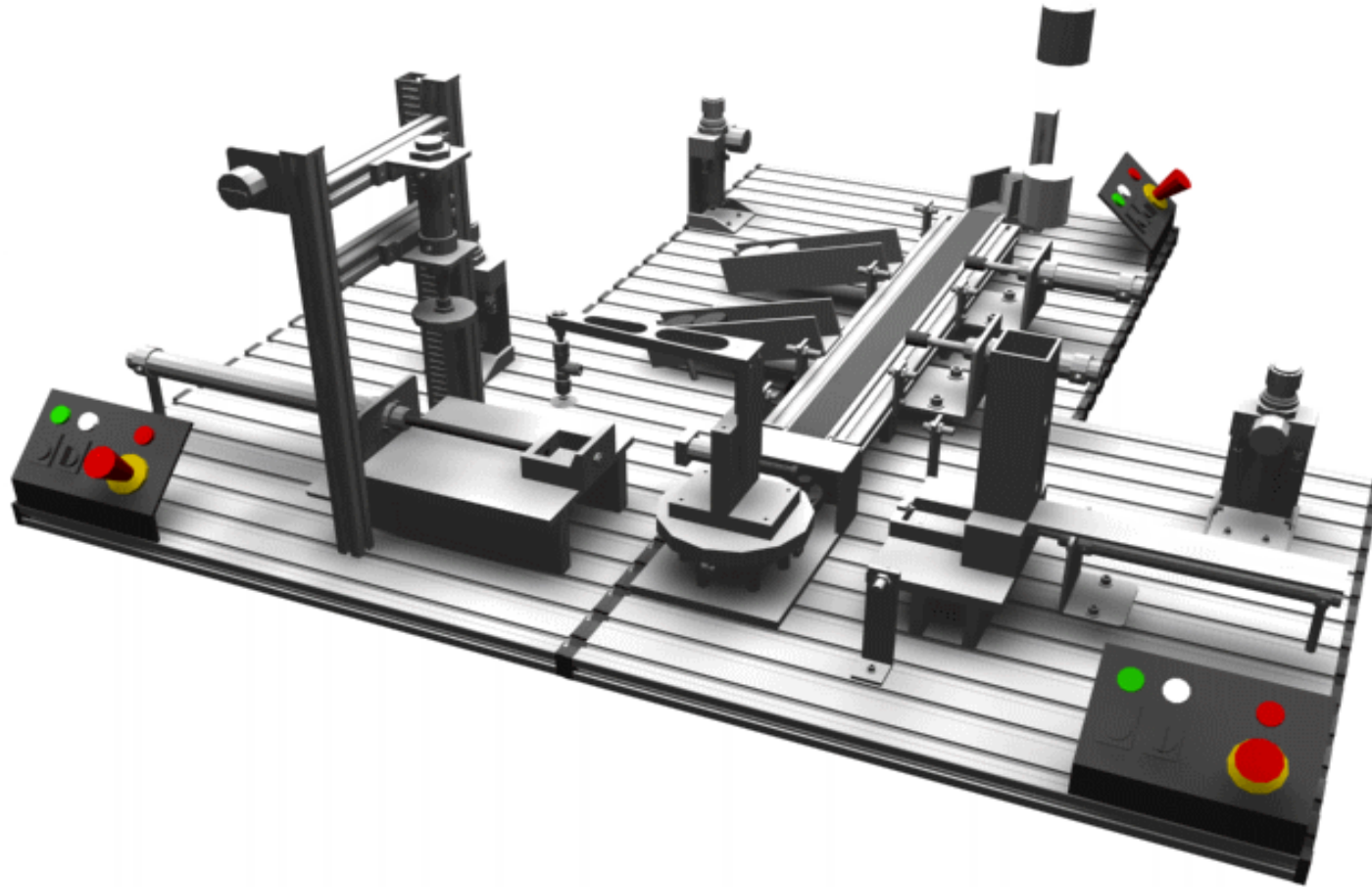




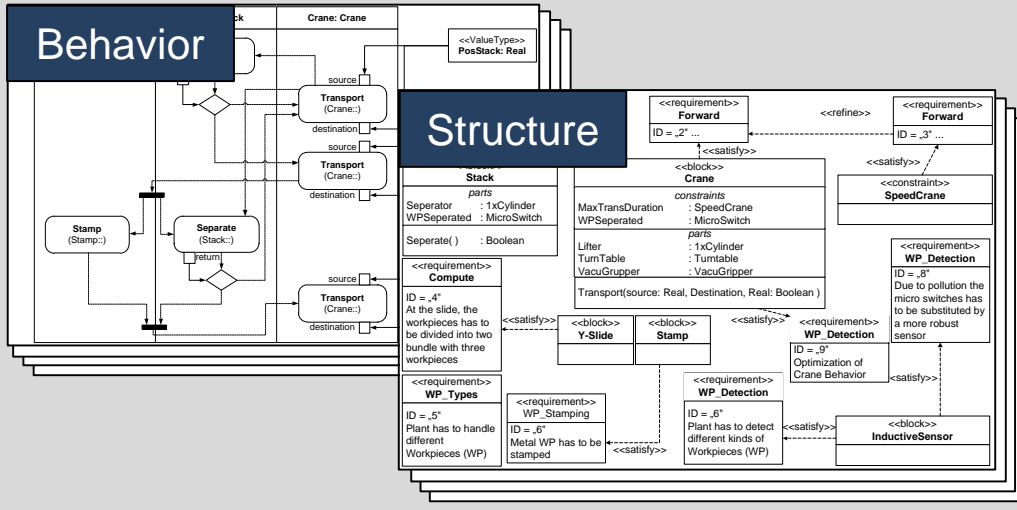
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## 16 SysML models with evolutionary changes



## Technical Documentations

Technical documentation for the PLC system, including hardware images and a device table.

**Connected to PLC Fieldbus + HW-Adresses**

**DC-Servomotor mit inkrementalem Wegmeßsystem**

**Unterdruckschalter**

**Positionierung des Mikroschalters, Drumpotentiometer (Analogeingang) inkrementalem Wegmeßsystem**

Group	Device	Function	Location	Device/SI-gnals type	Power supply [V]	Remarks
310	M1	sort/push WP in slide 1	pusher	pneum. valve DO	24V	mand.
310	B1.1	pusher is extended	pusher	reed switch DI	24V	mand.
310	B1.2	pusher is retracted	pusher	reed switch DI	24V	mand.
310	B1.4	position of pusher	pusher	distance sensor AI	24V	SHM
320	M1	sort/push WP in slide 2	pusher	pneum. valve DO	24V	mand.
300	B1	pressure sensor	valve node	pneum. meas. AI	0-24V	SHM

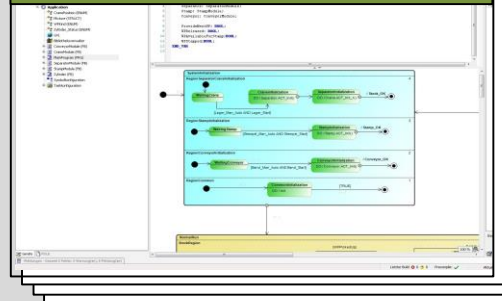
## PLC implementations

Especially for project *Pythia*:

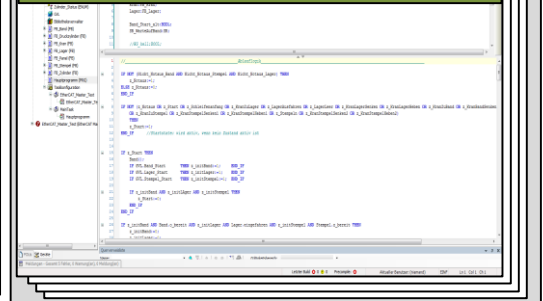
- 45 different IEC 61131-3 Projects
- graphical and textual programming languages

## 16 PLC implementations each

### Based on plcUML



### Classical IEC61131



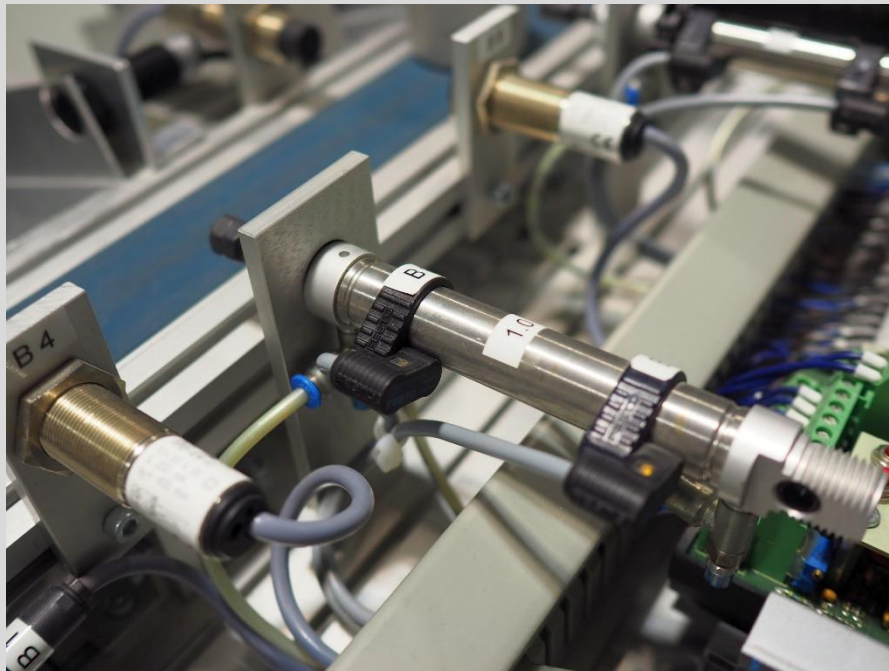
<https://mediatum.ub.tum.de/node?id=1208973>





Sc12f	Additional functionality self-healing machine and diagnosis	x	0	x	Additional sensors and software required, automatic mode enlarged
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## Sc12f: Additional Sensor for Fault Detection, Isolation and Handling



- **Binary Sensors** for discrete front and back position detection



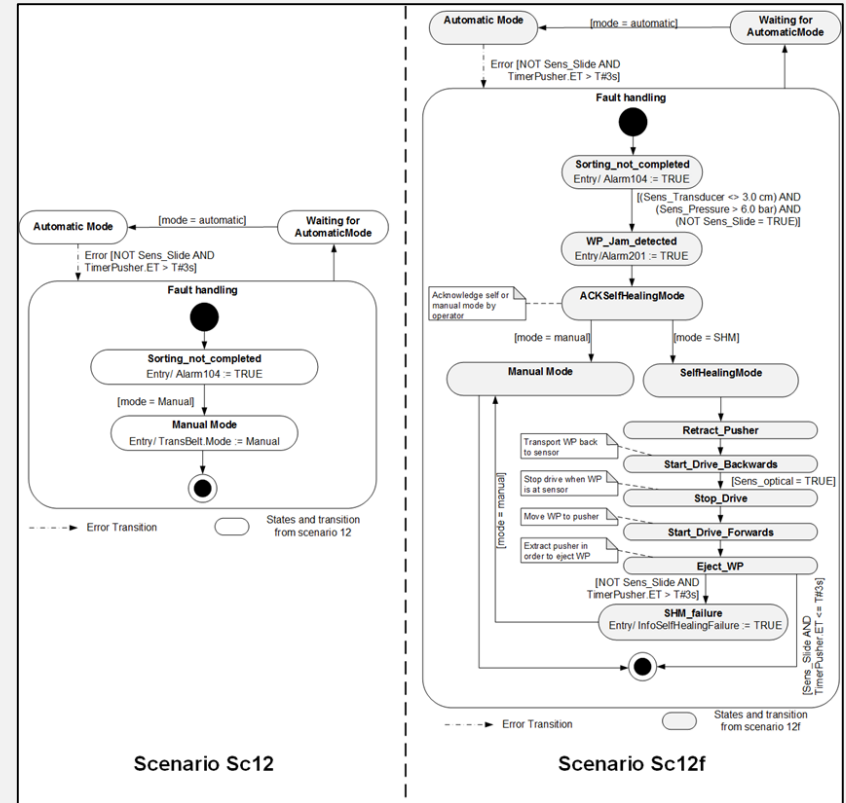
- **Additional analogue sensor** to detect exact position of pusher and redundancy for binary sensors
- Result: work piece jam → self healing mode



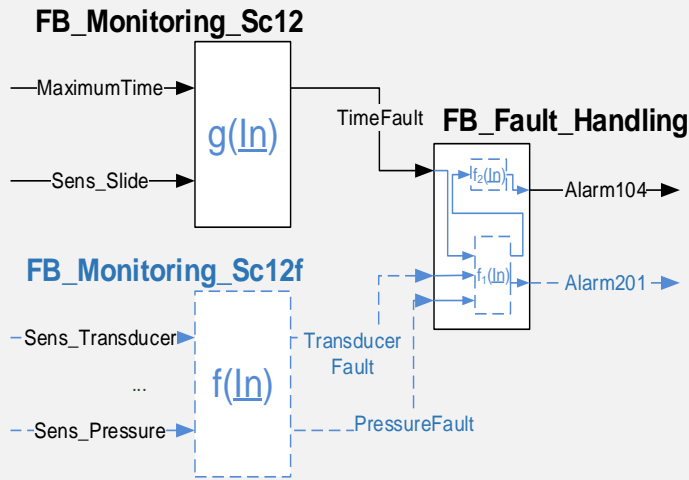
## Changes on component list/ sensor level (context)

Group	Device	Function	Location	Device/Si gnal type	P. supply [V]	Remarks
310	B1.1	pusher is extended	pusher	reed switch DI	24V	mand.
310	B1.4	position of pusher	pusher	distance sensor AI	24V	SHM
....	....	....	....	....	....	....
300	B1	pressure sensor	valve node	pneum. meas. AI	0-24V	SHM

## Changes on model level (software)



## Changes on code level (software)

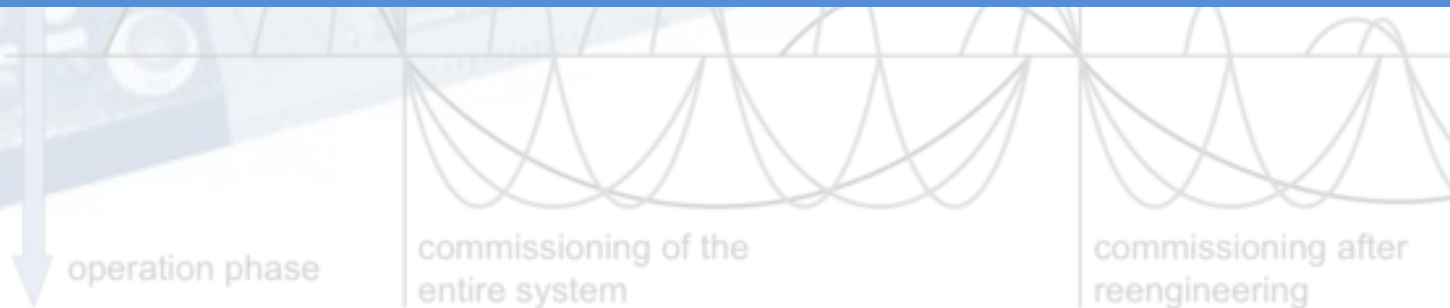




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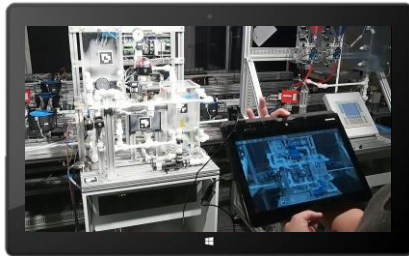
## 4. Conclusion and Outlook



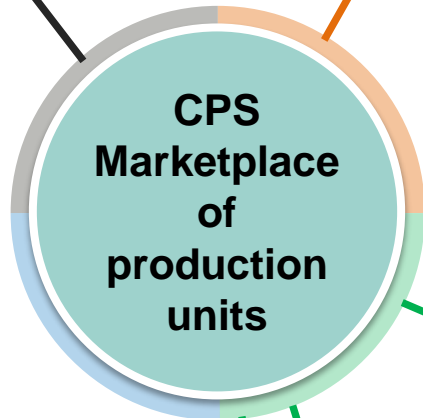
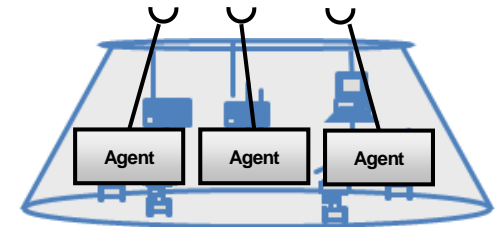


## Data processing for humans

Data processing and integration for humans

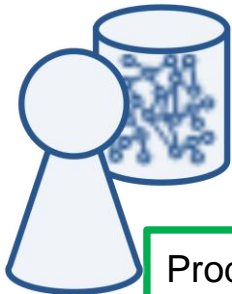


**Architecture models (reference architecture)** for a category of aggregation/modules related to properties, capabilities, interfaces...

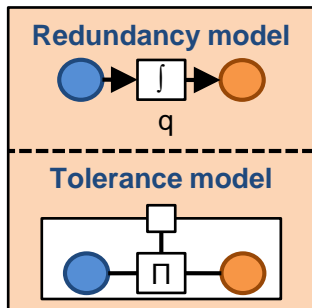


## Intelligent products and production units

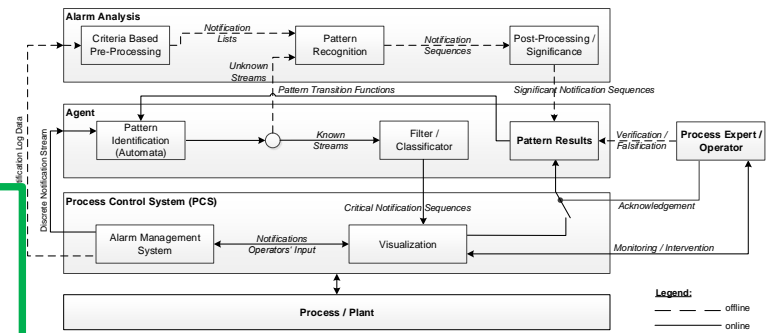
Data analysis of process and alarm data and connection with engineering data



Production units with **inherent capabilities**



**Flexible production units, adaptable to modified product requirements, allow also structural changes**



Compare: B. Vogel-Heuser, G. Bayrak, U. Frank: Forschungsfragen in "Produktautomatisierung der Zukunft". acatech Materialien. 2012.





# Summary and Outlook

- Industrie 4.0 demands new concepts for automation software during engineering (software development) and during runtime
- Changes during runtime are mandatory for Industrie 4.0
- Reconfiguration of production processes for customized products
- Compensation of sensor faults to increase the availability of aPS
- Self-Healing Mode for smart diagnosis and maintenance
- **Metrics** have to be developed for benchmarking Industrie 4.0 compliant aPS
- Open demonstrator for software evolution of an aPS at the PPU
- Joined demonstrator Myjoghurt is open for cooperation
- **@education** – e-learning environment with automatic evaluation of programs, Boolean algebra, simulation interfaces for PPU



<http://i40d.ais.mw.tum.de>



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- **M. Kowal, C. Legat, D. Loreface, C. Prehofer, I. Schäfer, and B. Vogel-Heuser:** Delta modeling for variant-rich and evolving manufacturing systems. 36th International Conference on Software Engineering Workshops (ICSE), 2014, pp. 32-41.
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- **M. Lochau, J. Bürdek, S. Lity, M. Hagner, C. Legat, U. Golz, and A. Schürr:** Applying Model-based Software Product Line Testing Approaches to the Automation Engineering Domain. at – Automatisierungstechnik, Vol. 62, Nov. 11, 2014.