ICoMST 2019

Digital transformation in the food industry –

Opportunities, challenges and solution approaches from the perspective of ongoing research projects

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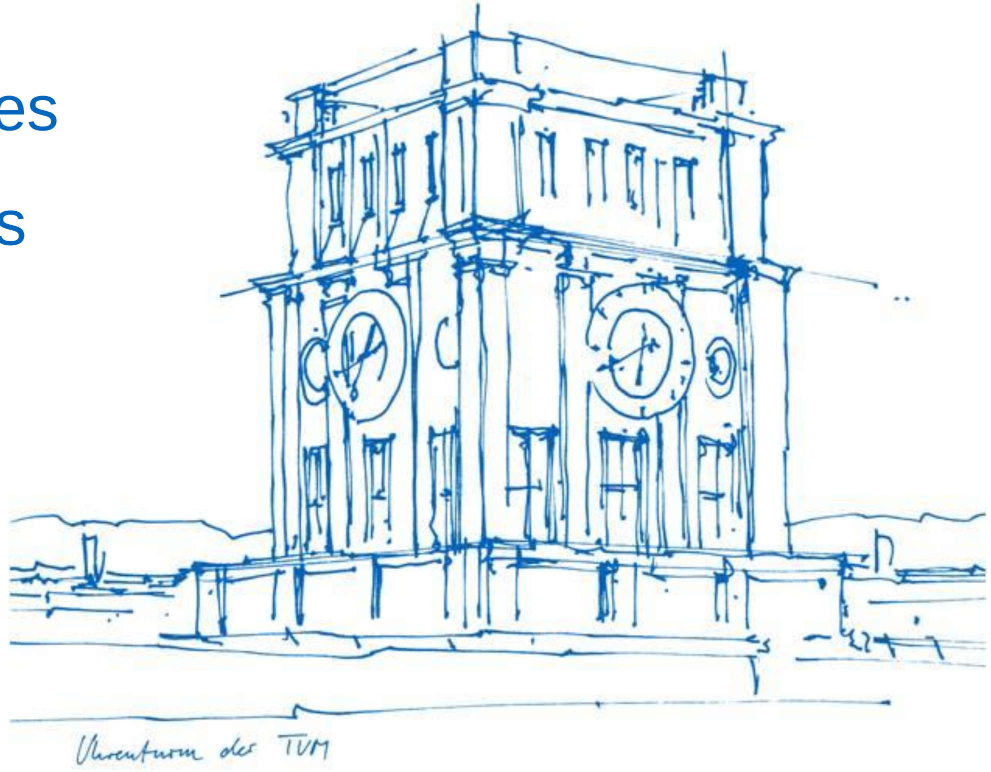
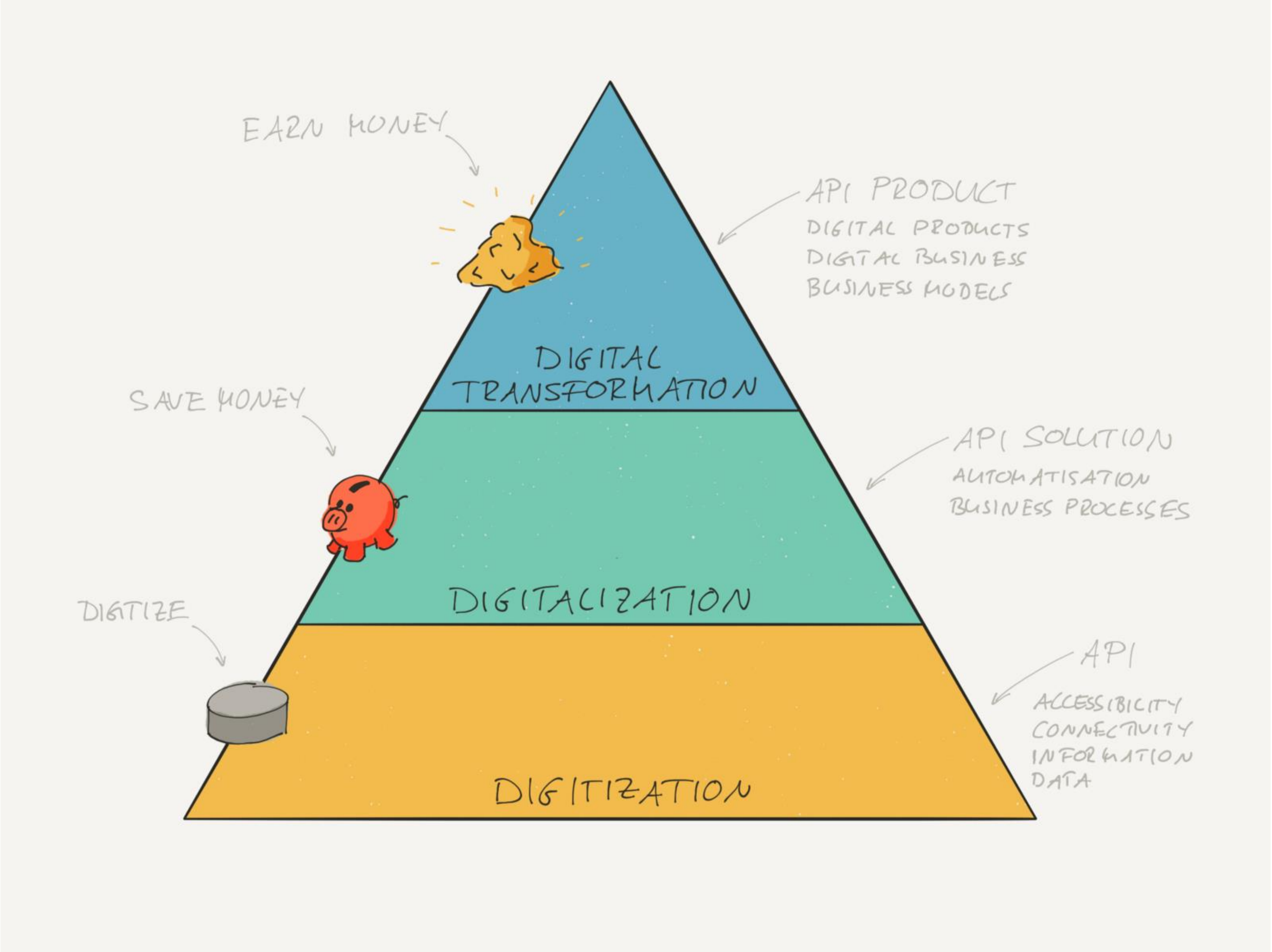


Digital Industry – Levels and Terms



[medium.com/api-product-management, 2019]

Digital Transformation

- Digital Products
- Digital business models

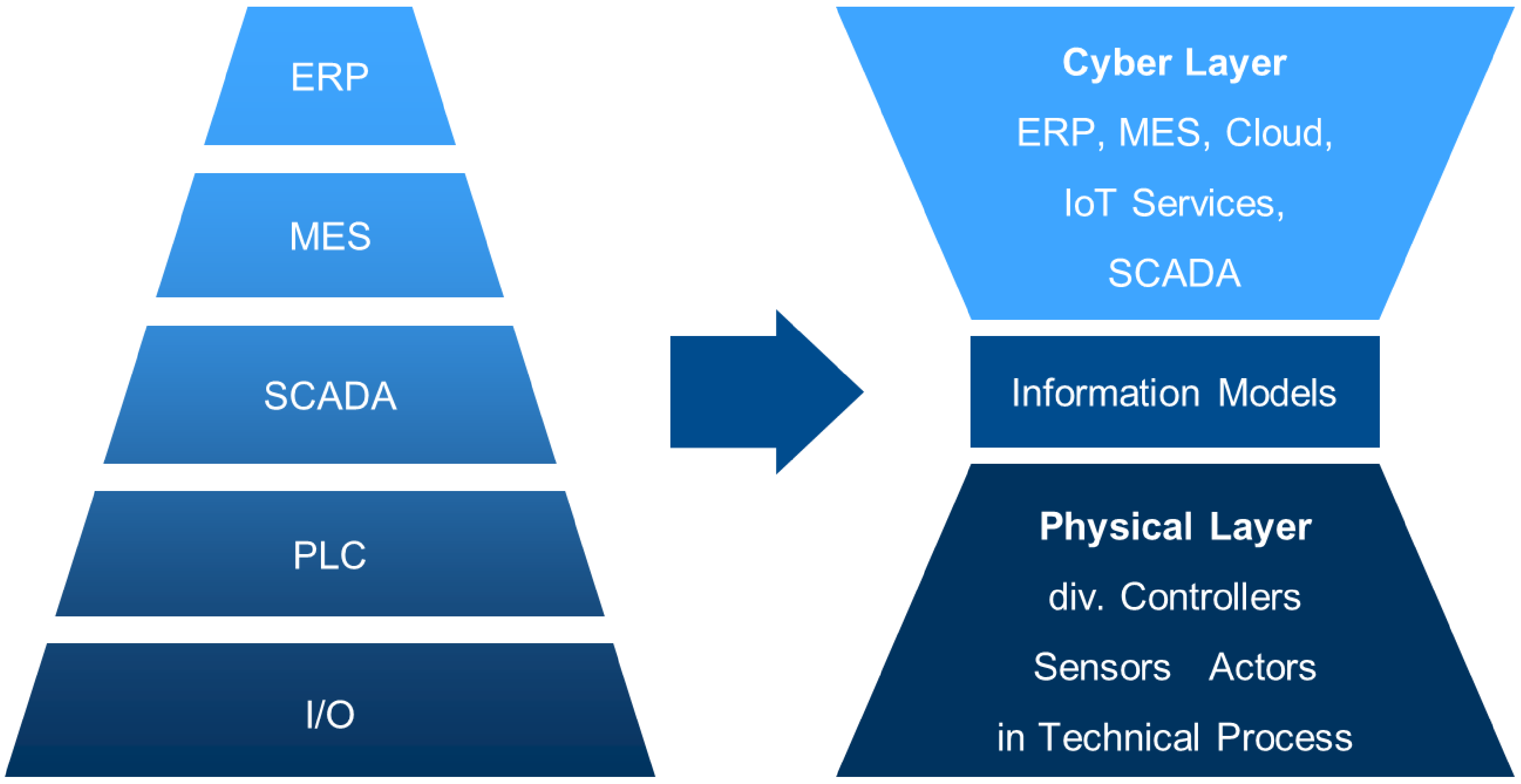
Digitalization

- business processes
- manufacturing management
- automation

Digitization

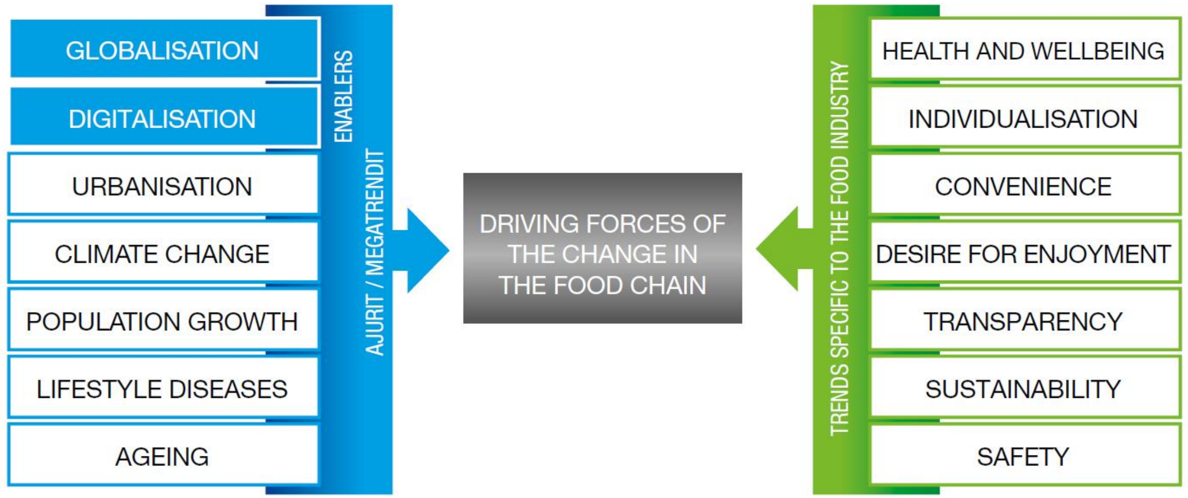
- exchange of data
- interconnectedness
- Analog-to-digital conversion

From Automation Pyramid to Cyber Physical Production Systems



Objectives of the food industry

- cost reduction
  - ➢ increase in productivity
  - ➢ saving of resources
  - ➢ Improved production processes
- Stronger networking of the supply chain
  - ➢ Transparency and security
  - ➢ traceability
- Better product quality
  - ➢ Avoidance of food losses
  - ➢ Process stability with fluctuating raw materials
- Greater flexibility
  - ➢ Increasing the reaction speed
  - ➢ More customized products



[Food economy 4.0 –
VTT’s vision of an era of smart consumer-centric food production, 2018]

→ each **digital representation** challenge requires adequate **modelling** approaches

Information Models for the Food Industry - Weihenstephan Standards (WS)

Standard interface

- Ethernet Socket
- Proprietary commands
- Test Tool

Data contents

- Tagnames/ numbers
- Data types
- XML Device description

Data Evaluation

- Efficiency Analysis
- Batch Tracing
- Quality Assurance

Example of a Standard WS Data Point

Name:	Total Bottles
Tag-Number:	50005
Tag-Name:	WS_Tot_Bottles
Data Type:	Unsigned32
Read/ Write:	R
Description:	This data point provides the number of bottles processed in the machine

Additional data points may be defined with a different prefix according to specified rules, e. g. data point from company XYZ AG (Bottle capper)

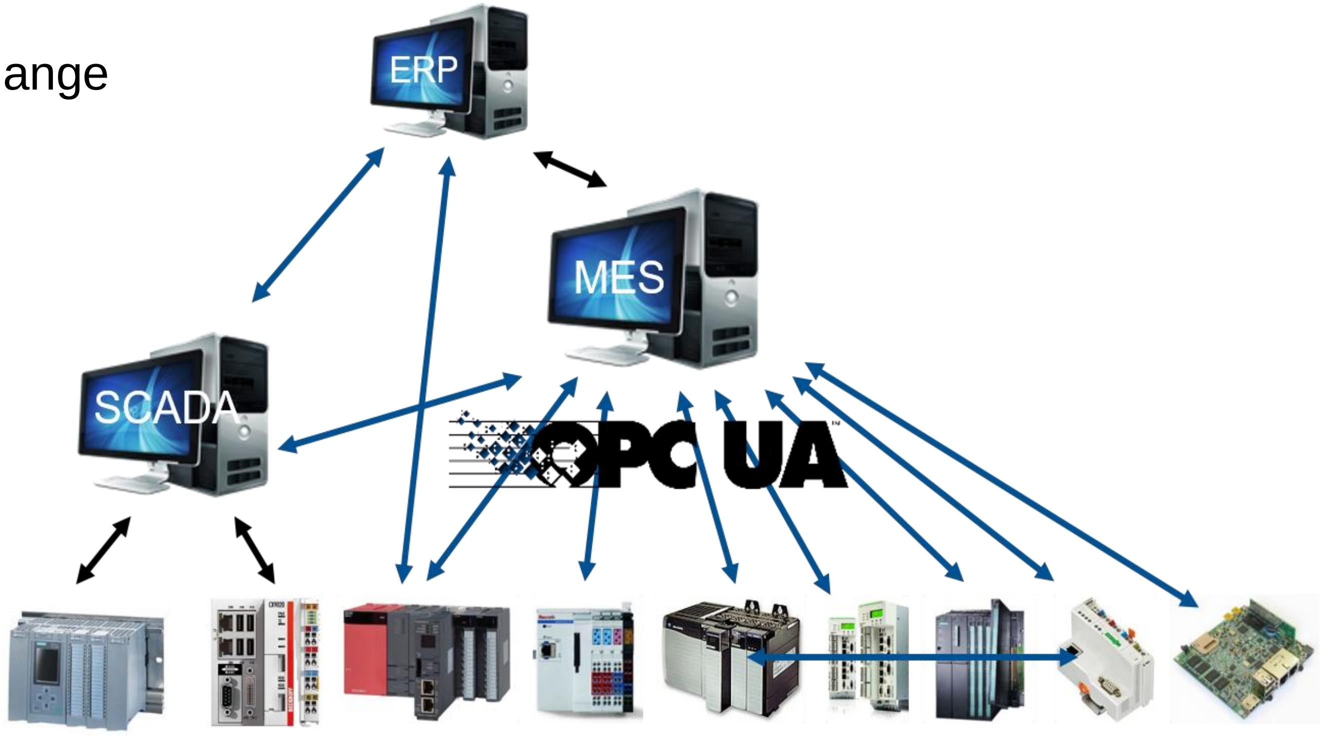
Name:	closure force
Tag-Number:	31101 (from free area for parameters)
Tag-Name:	XYZ_Closure_Force
Data Type:	Unsigned32
Read/ Write:	RW
Description:	Data Point provides the closure force for a closing stamp in N.

WS goes OPC UA

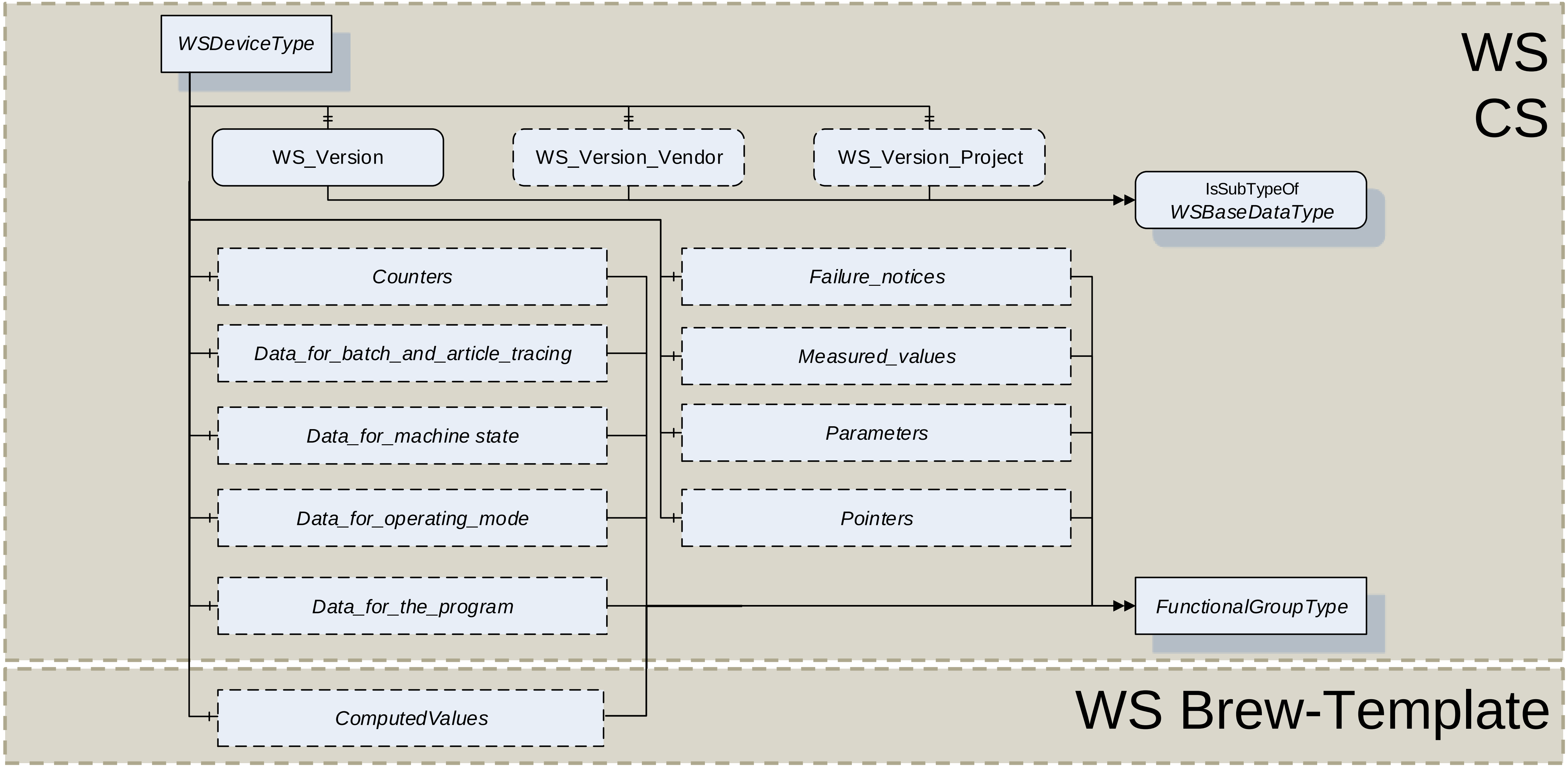
Alternative to current WS communication protocol (based on TCP/IP)

Pros:

- Bidirectional communication, fast data exchange
- Available on all relevant PLCs
- No license costs
- System independent
- Availability of all data
- Direct access to the PLC



WSDeviceType



Data profile libraries for different machine types

MES Modelling

MES Project						
1. Basic Evaluation	2. Pre-Planning Stage	3. Basic Planning	4. Detailed Design	5. Implementation Stage	6. Operation Stage	7. Project Completion

State of the art:

- Customization
- Specialization
- Parametrization

Consequence:

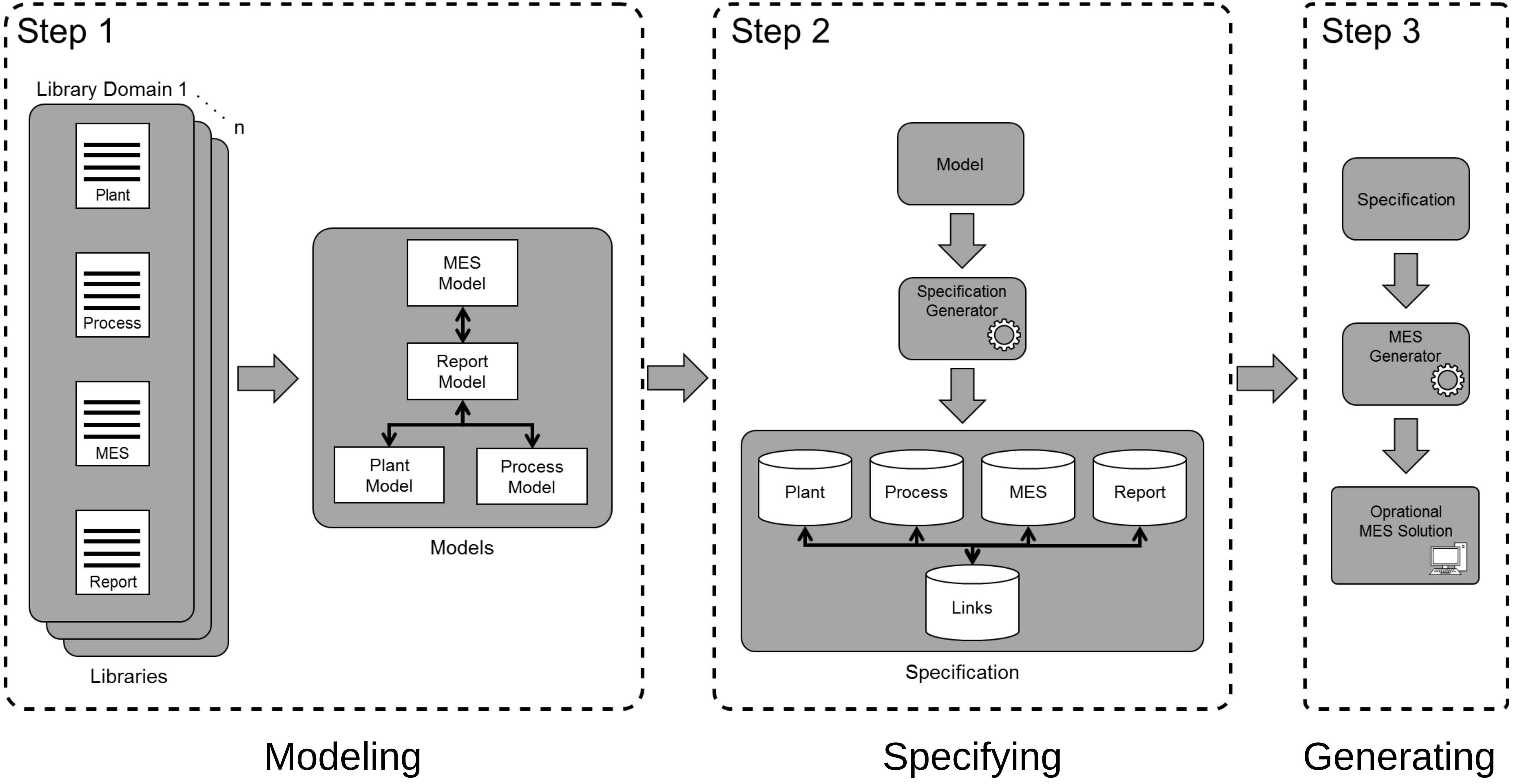
- Personnel expenditure
- 90 % Software
- 10 % Hardware

Motivation:

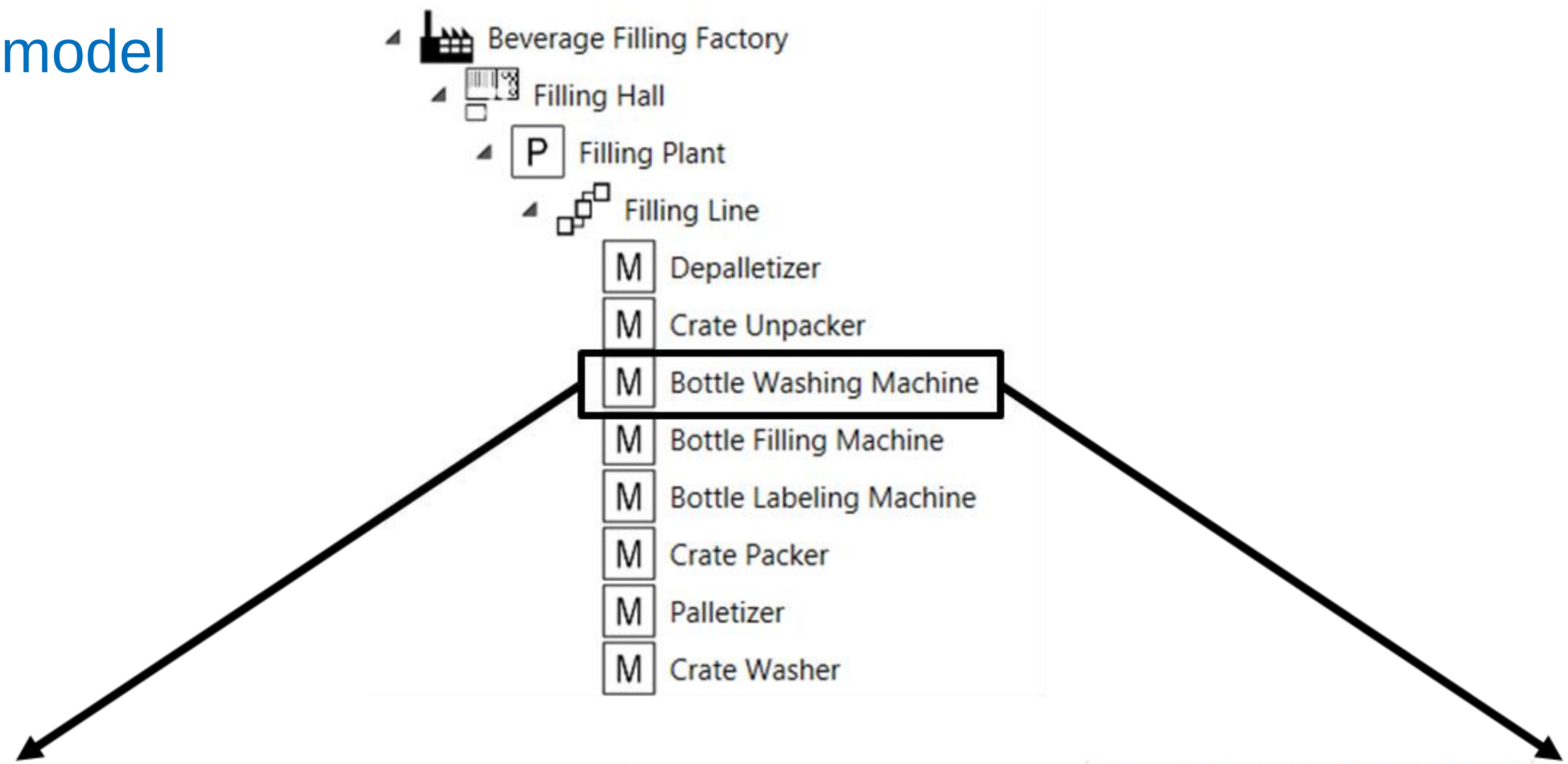
- Concepts & Methods
- Saving Potential
- Reduction of Cost

Model-driven Engineering of Manufacturing Execution Systems

Model-driven approach for MES Generation



Beverage filling line – plant model



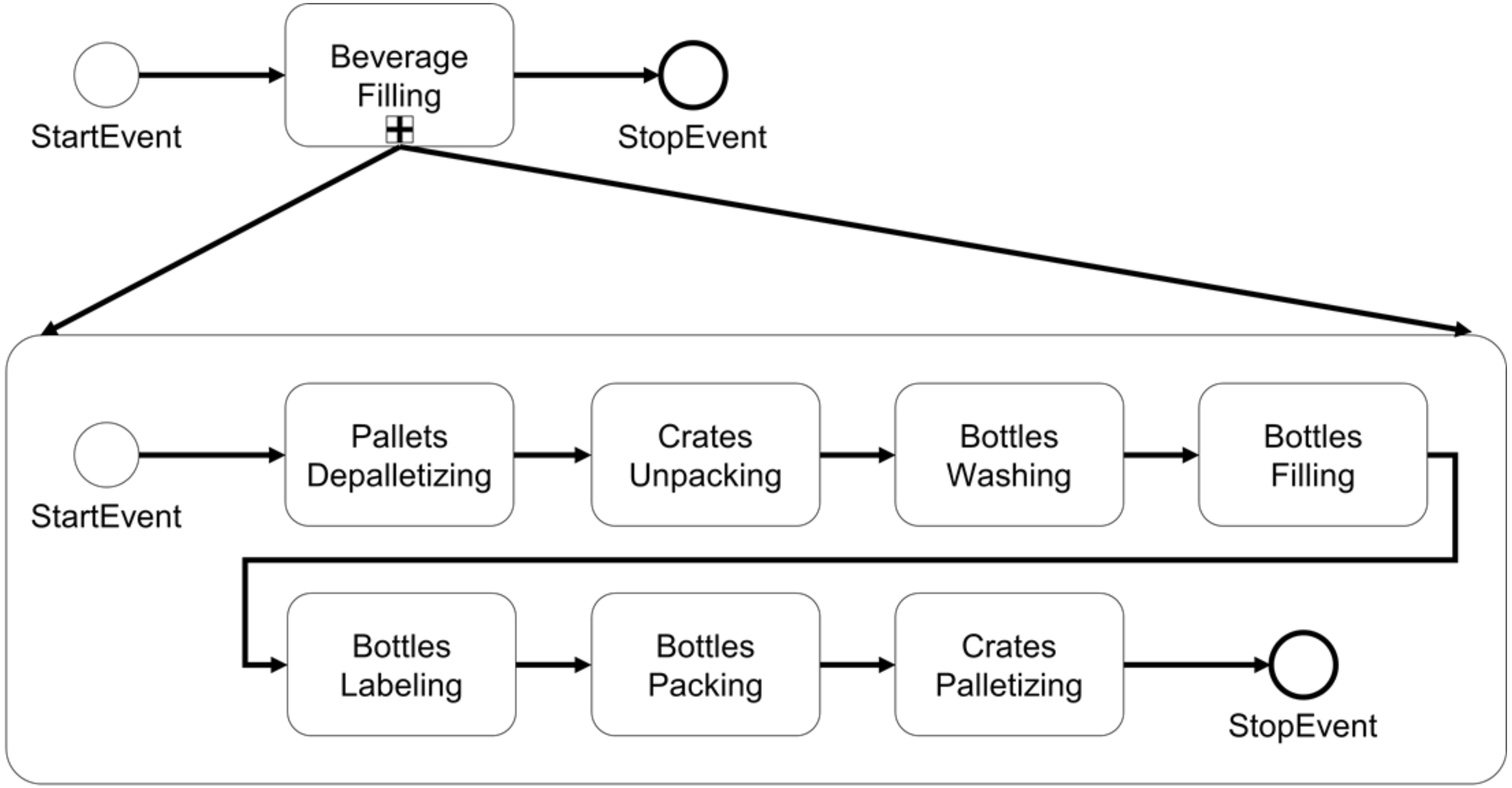
WS	00100 - WS_Cur_Mode	WS_Mode	Betriebsart. Informiert hierbei über Ar Die Betriebsarten können nur "exklusi
WS	00200 - WS_Cur_Prog	WS_Prog	Program. The program is a consequer function (DIN 19237).
WS	00300 - WS_Cur_State	WS_State	During the execution of the planned
WS	50101 - WS_Cons_Clean_Water	WS_Cons	Clean water consumption
WS	50102 - WS_Cons_Hot_Water	WS_Cons	Hot water consumption
WS	50110 - WS_Cons_Electricity	WS_Cons	Electrical power consumption

Beverage filling line – process model

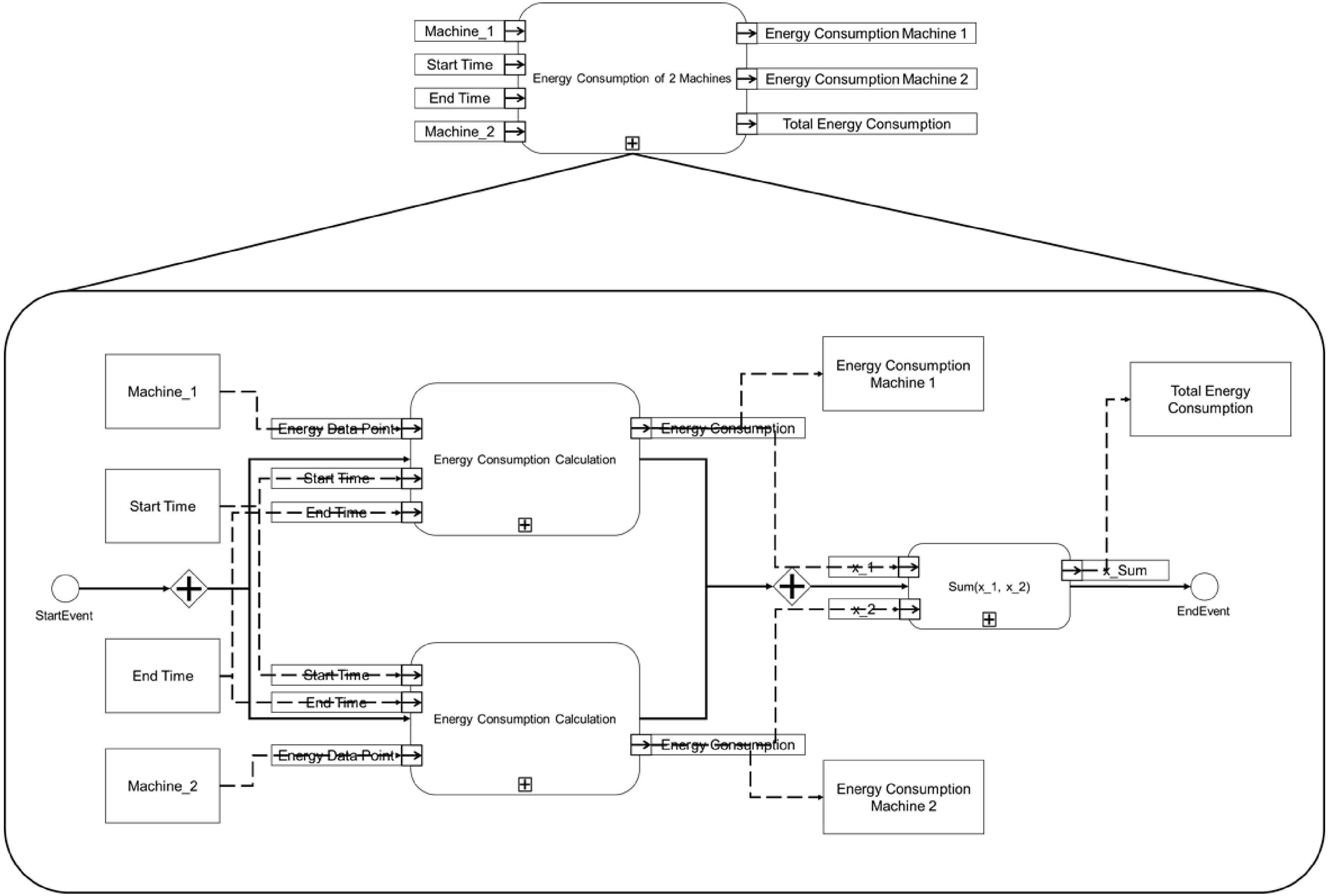
Process

Process Stage

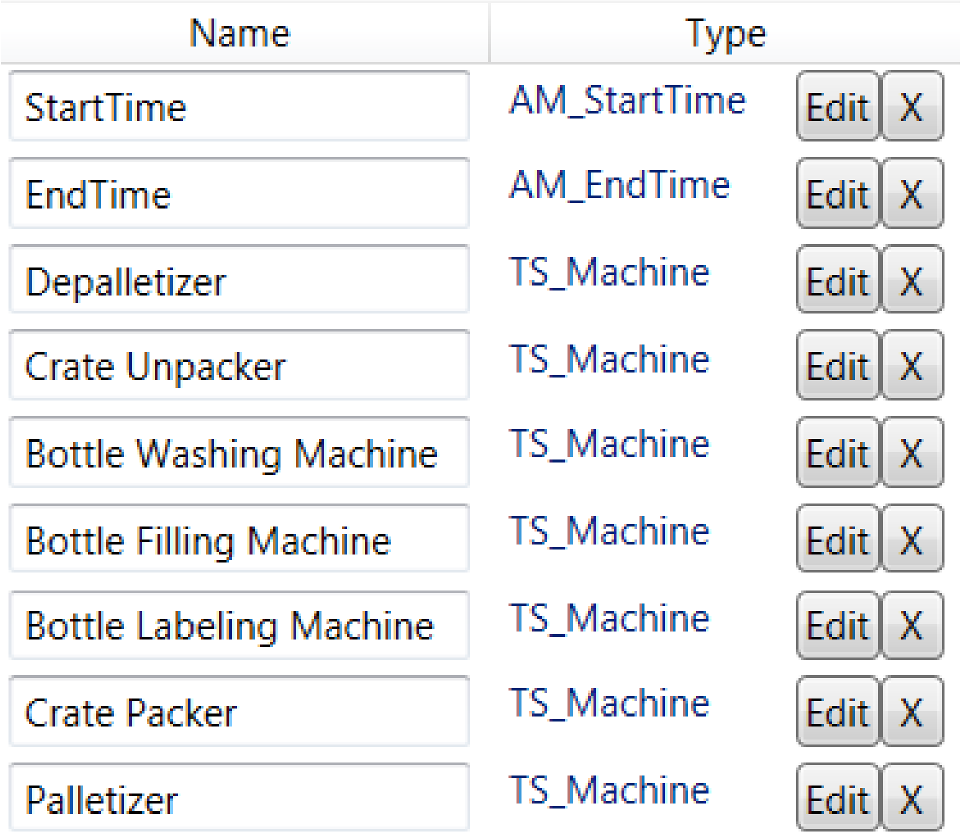
Process Operation

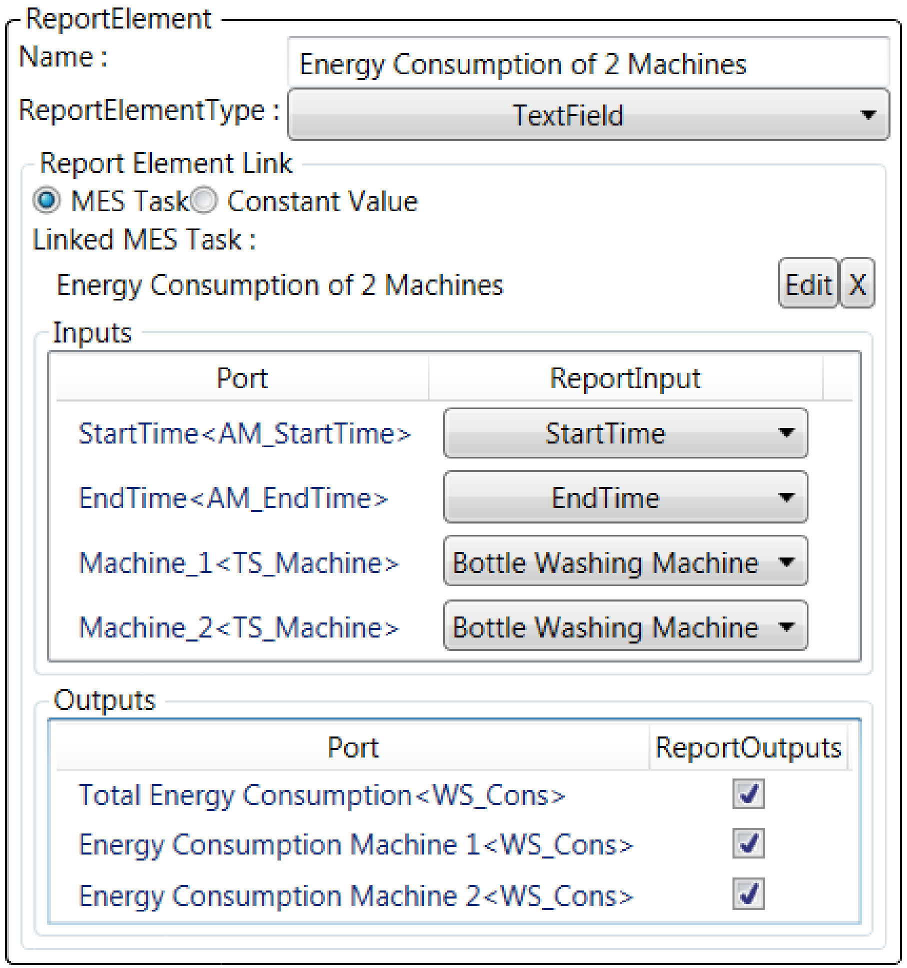


Beverage filling line – MES function model

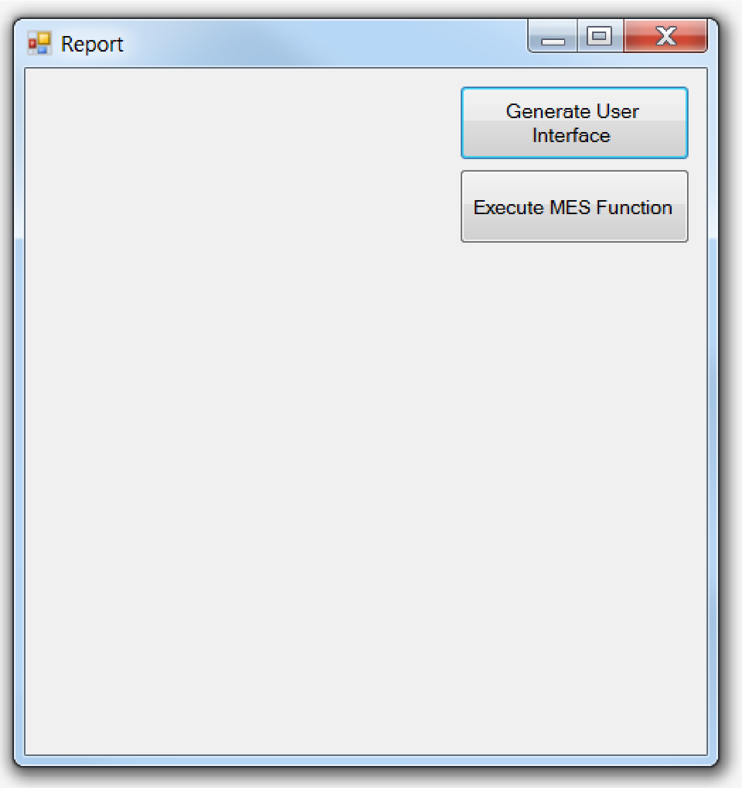


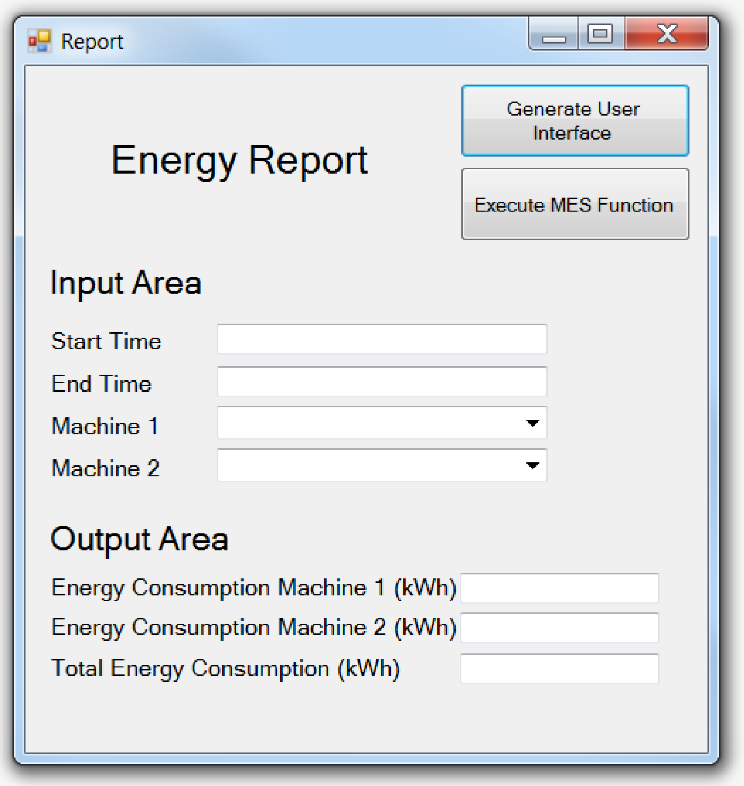
Beverage filling line – report model

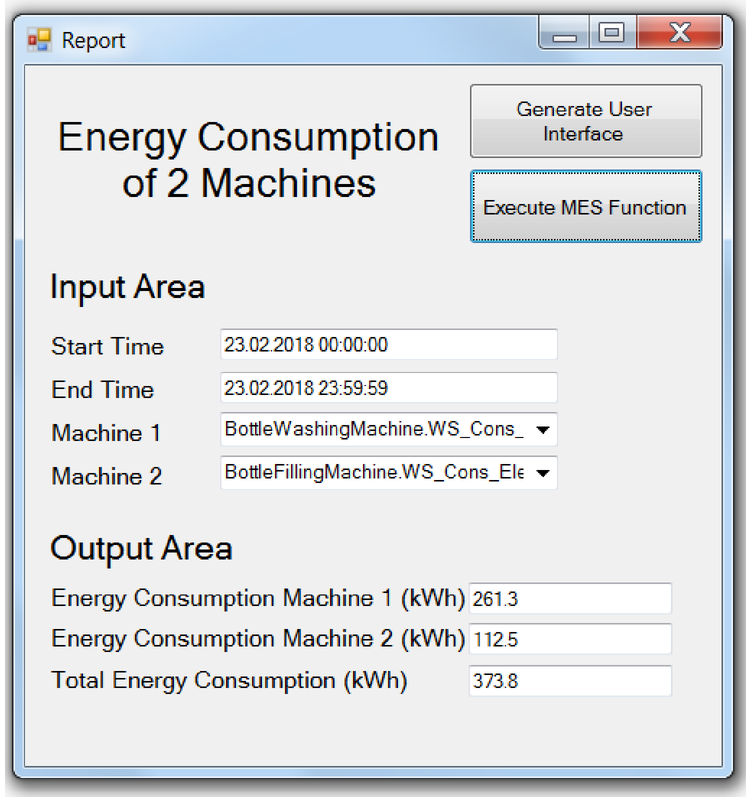




Beverage filling line – prototype of generator



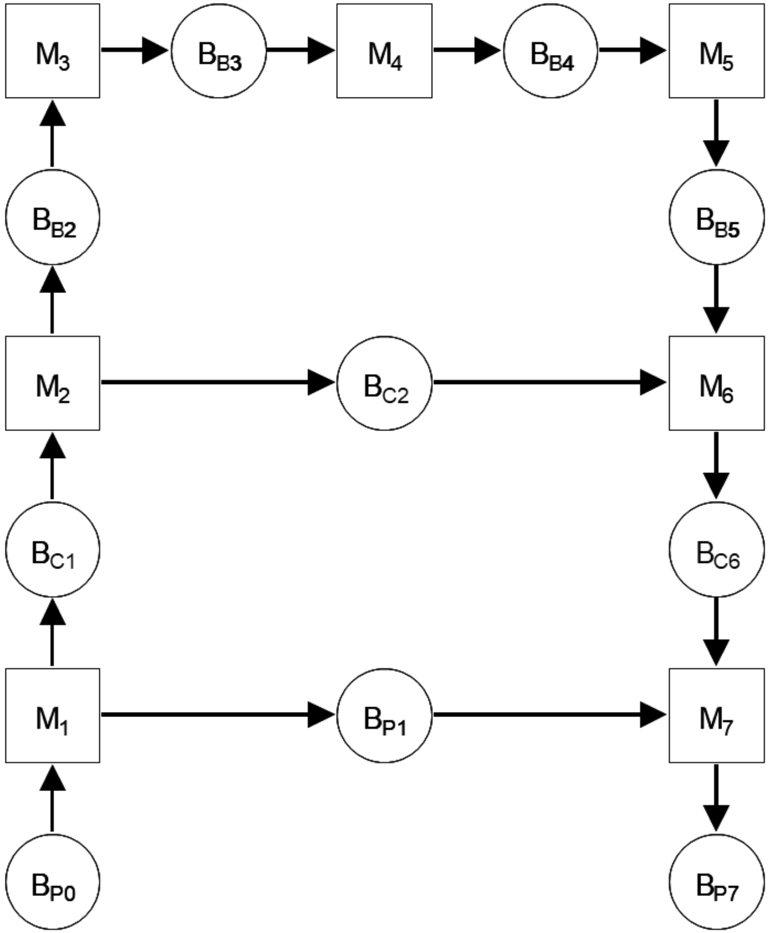




Model-based fault localization in bottling plants

Conveyors connecting machines of a bottling plant for returnable bottles

[Photo: Deutscher Brauer-Bund e.V.].



M_1 Depalletizing
M_2 Unpacking
M_3 Bottle cleaning
M_4 Bottle inspection, filling and capping
M_5 Labeling
M_6 Packing
M_7 Palletizing

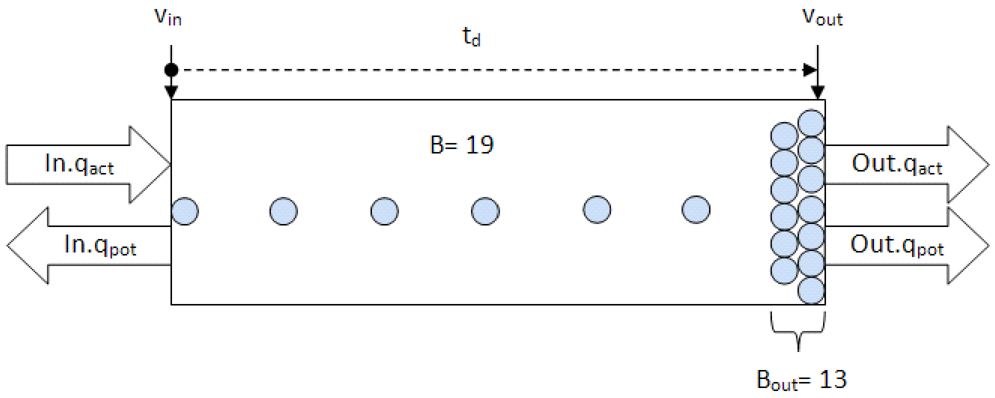
B_{P0} Pallet feeding
B_{P1} Pallet transport incl. magazine
B_{P7} Pallet releasing

B_{C1} Crate conveyor
B_{C2} Empty crate conveyor incl. cleaning and magazine
B_{C6} Crate conveyor

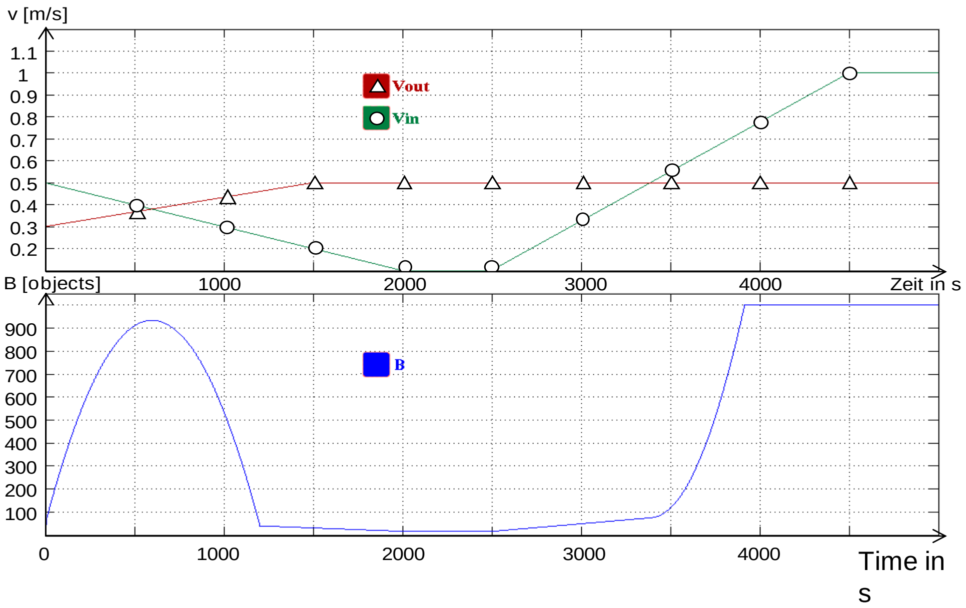
$B_{B2\text{-}5}$ Bottle conveyors

Generic structure of a bottling plant for returnable bottles

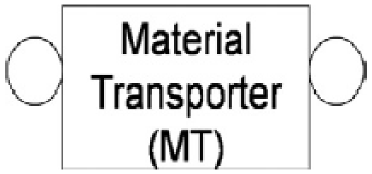
Physical Component Models



Schematic model of the Material Transporter



Buffer response (lower graph) to variation of v_{in} and v_{out}



State variables

B	Objects in buffer (#objects)
B_{out}	Objects buffered for immediate output (#objects)
v_{in}	Velocity of input transportation means (m/s)
v_{out}	Velocity of output transportation means (m/s)
t_d	Minimal transportation time (s)

Parameters

d_0	Diameter of transported object (in transportation plane) (m)
C	Capacity (#objects)

Interface variables

$in.q_{pot}$	Potential inflow (#objects/s)
$out.q_{pot}$	Potential outflow (#objects/s)
$in.q_{act}$	Actual inflow (#objects/s)
$out.q_{act}$	Actual outflow (#objects/s)

Equations

(1) $in.q_{pot}(t) = v_{in}(t)/d_0$ if $B(t) < C$

$in.q_{pot}(t) = \min\,(v_{in}(t)/d_0,\ out.q_{act}(t))$ if $B(t) = C$

(2) $dB/dt = in.q_{act}(t) - out.q_{act}(t)$

(3) $out.q_{pot}(t) = v_{out}(t)/d_0$ if $B_{out}(t) \geqslant 1$

$out.q_{pot}(t) = \min\,(in.q_{act}(t - t_d),\ v_{out}(t)/d_0)$

else

(4) $dB_{out}(t)/dt = in.q_{act}(t - t_d) - out.q_{act}(t)$

Qualitative Models allow **consistency-based diagnosis**

Material Transporter (MT) with Buffer

[1] $[in.q_{pot}(t)] = [v_{in}(t)]$ if $C\text{-}B(t) > 0$

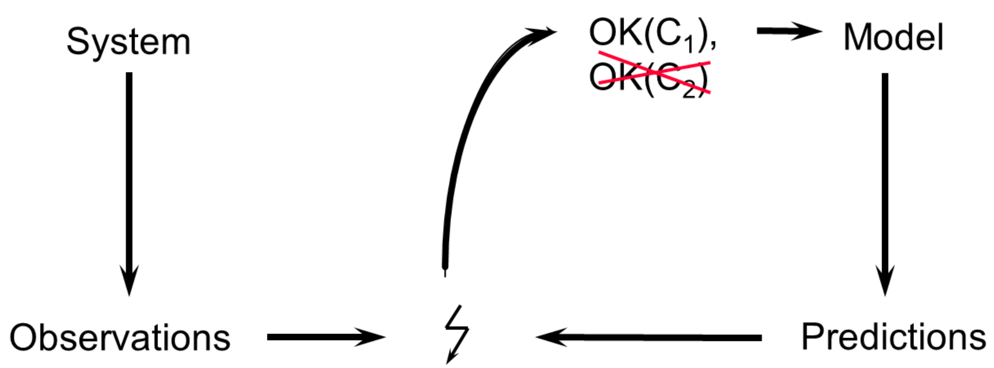
$[in.q_{pot}(t)] = \min([v_{in}(t)], [out.q_{act}(t)])$ if $C\text{-}B(t) = 0$

$[in.q_{pot}(t)]$	$[v_{in}(t)]$	$[out.q_{act}(t)]$	$[C\text{-}B(t)]$
0	0	*	+
+	+	*	+
+	+	+	0
0	0	+	0
0	+	0	0

[3] $[out.q_{pot}(t)] = [v_{out}(t)]$ if $B_{out}(t)-1 \geq 0$

$[out.q_{pot}(t)] = \min([in.q_{act}(t - t_d)], [v_{out}(t)])$ if $B_{out}(t)-1 < 0$

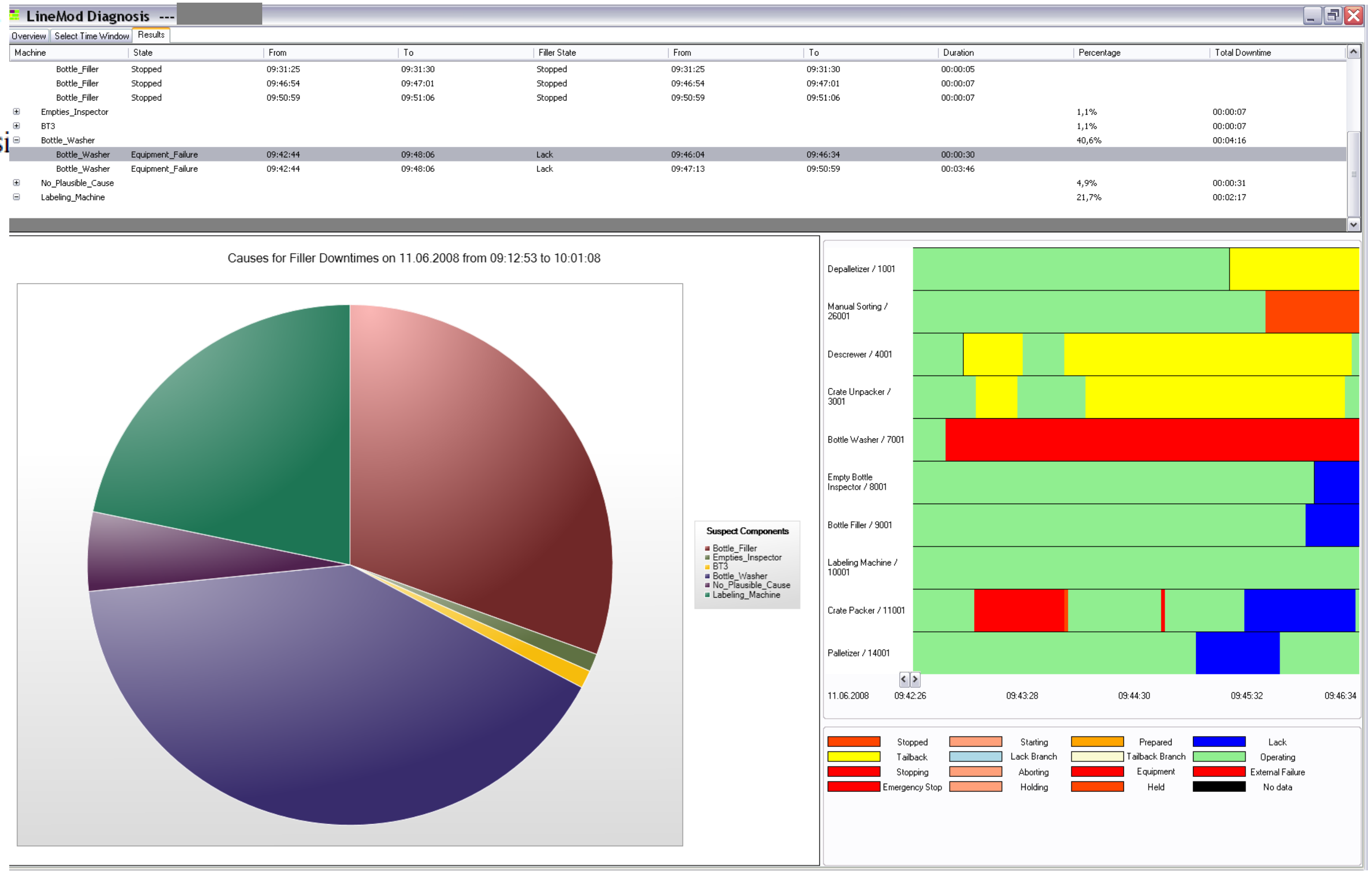
$[out.q_{pot}(t)]$	$[v_{out}(t)]$	$[in.q_{act}(t - t_d)]$	$[B_{out}(t)-1]$
0	0	*	0
0	0	*	+



Principle of consistency-based diagnosis

Evaluation of results for the diagnosis solution

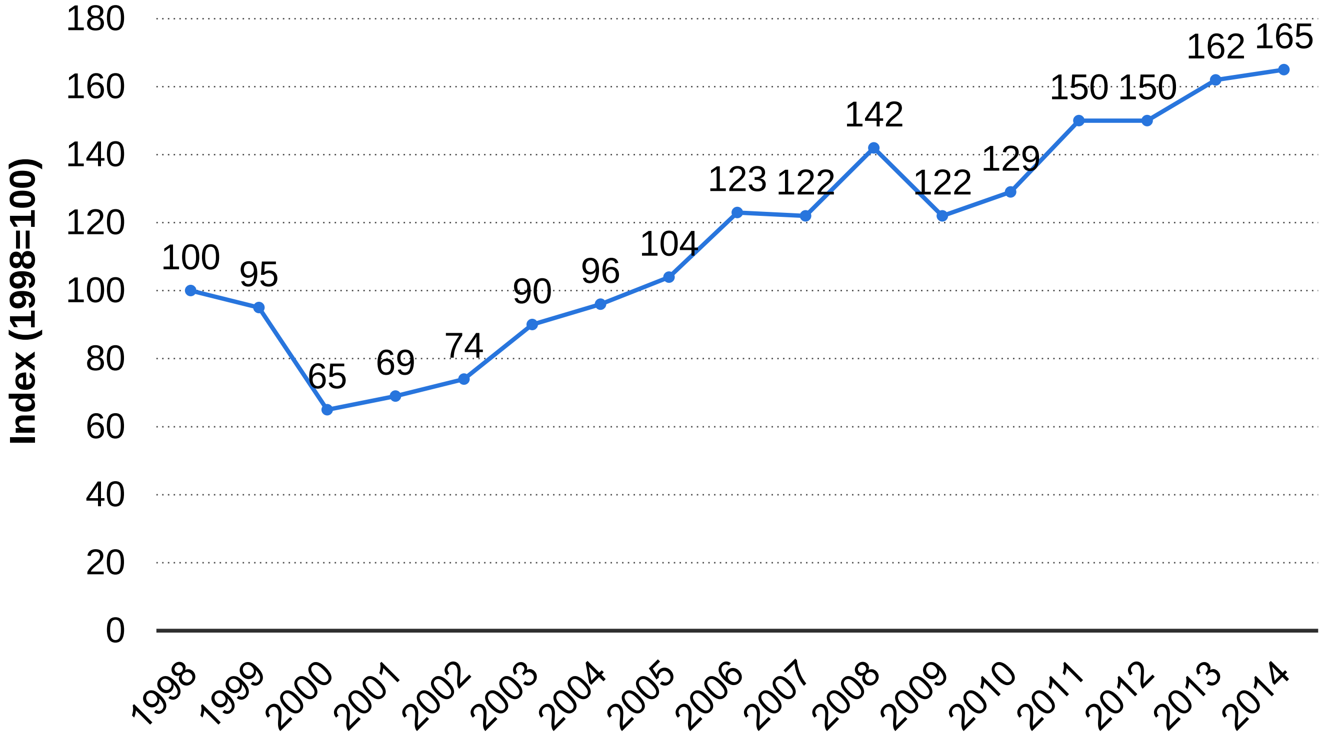
	Real plant A		Real plant B		Sum real plants A and B		Simulated plant C	
	Cases	Percent	Cases	Percent	Cases	Percent		Percent
Failures					312	64.7	0	0.0
					126	26.1	46	59.7
					44	9.1	31	40.3
Diagnosi					460	95.4	80	100.0
					22	4.6	0	0.0
					148	*87.1*	80	100.0
					22	*12.9*	0	0.0



Implementation (screenshot) into an industrial diagnosis tool

Energy simulation in food production systems

- Rising energy cost (especially electric)
- Energy consumption of packaging machinery strongly related to production state
- Prognosis necessary for optimisation
- State related forecast solutions are missing

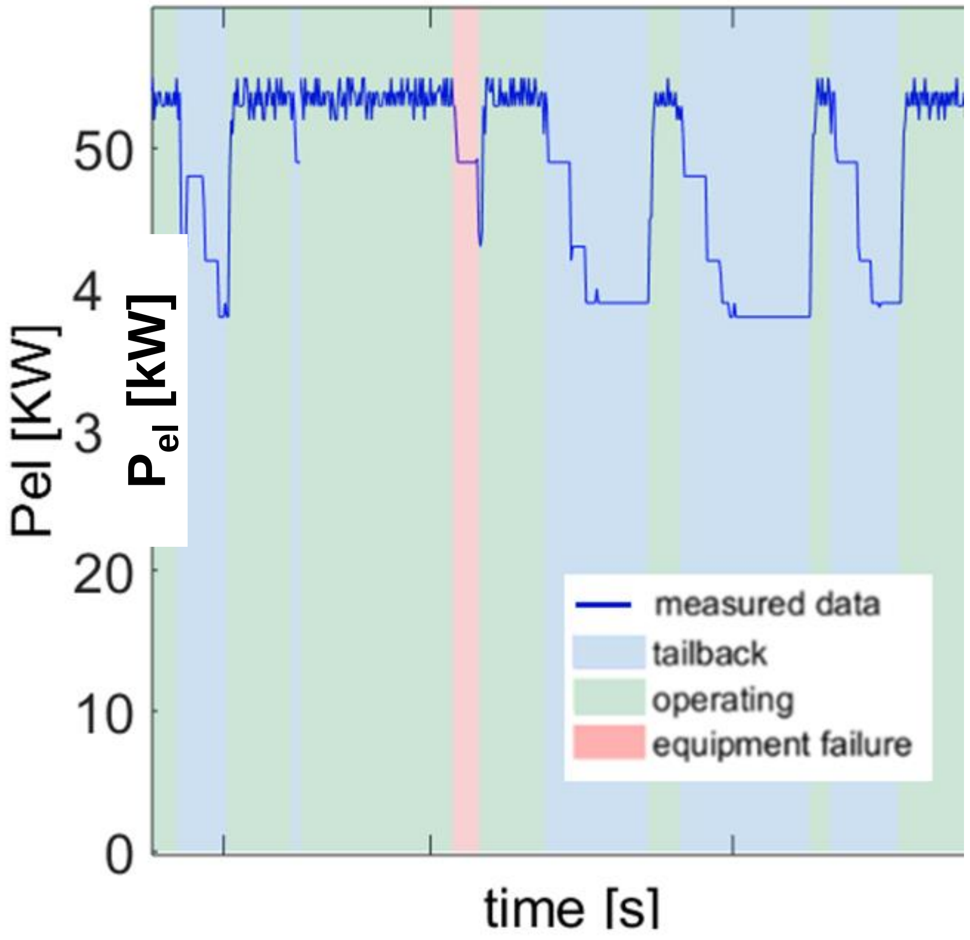


Index of the development of industrial electricity prices *
in Germany in from 1998 to 2014 (1998 = Index 100)
[BDEW; Federation of energy consumers, 2015]

➔ Goal:

operational state related modelling and simulation to forecast the electric energy consumption

Data Acquisition and Modelling Approach



Power consumption and production states of the bottle cleaning machine

Measurements at an industrial bottling and packaging plant consisting of 10 machines

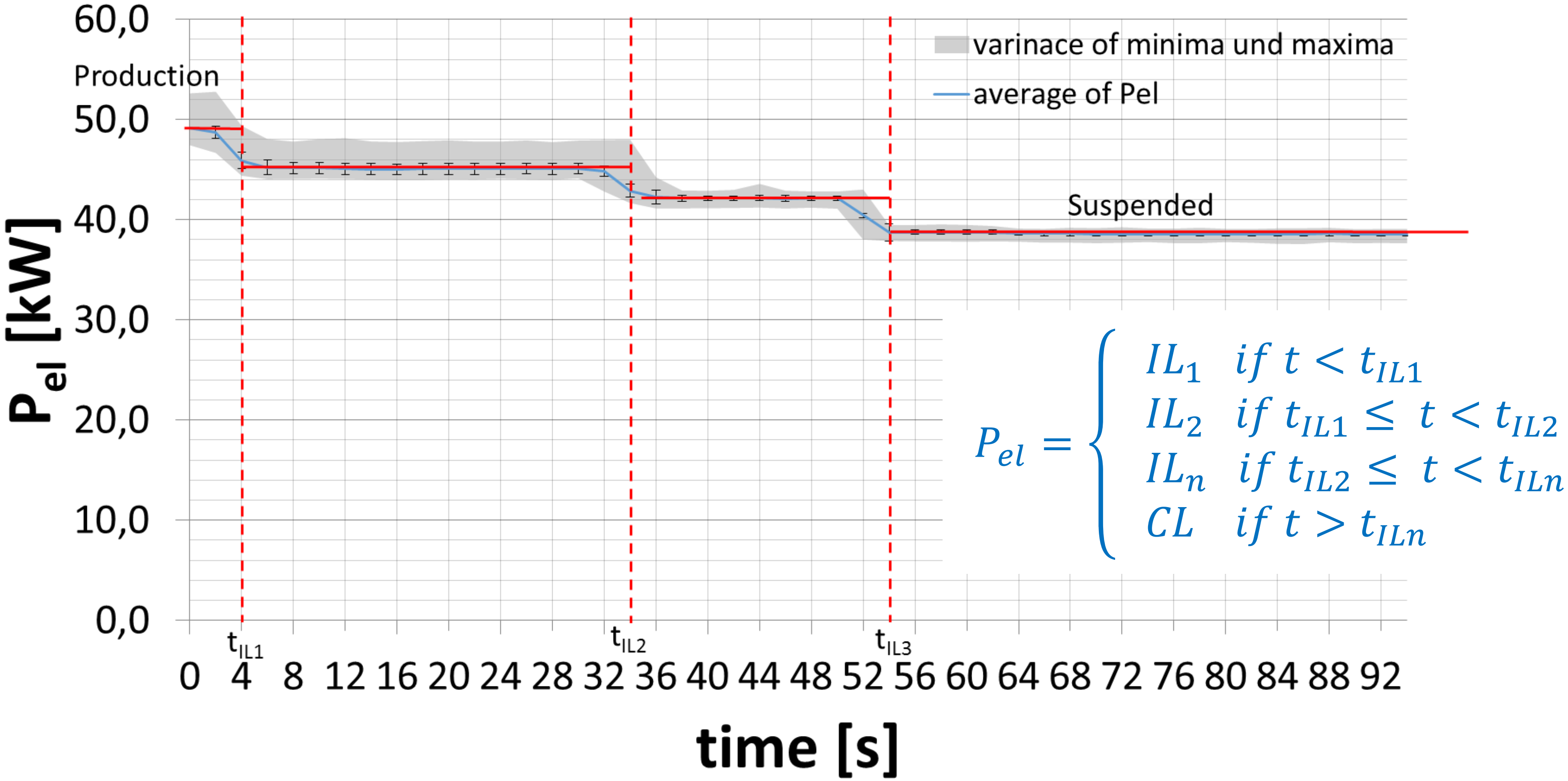
- Production state (operating, failure, held, emergency stop, lack, tailback, idle, prepared)
- Electrical power

Basic modelling idea:

Energy consumption of a machine is correlated with its energetic states at three constant levels:

- Producing
- Suspended
- Inactive

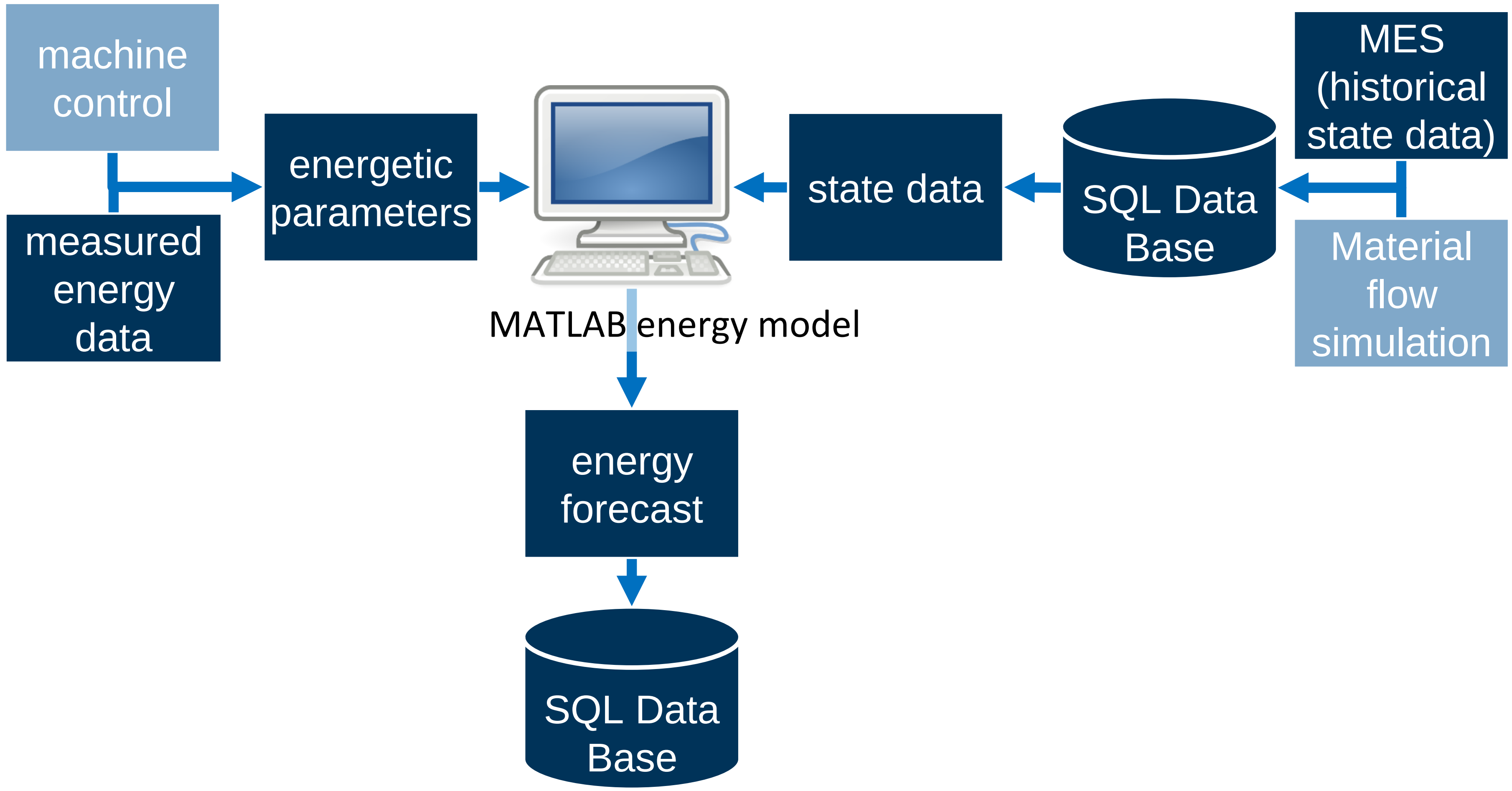
Modelling state changes along intermediate consumption levels IL



$$P_{el} = \begin{cases} IL_1 & if\ t < t_{IL1} \\ IL_2 & if\ t_{IL1} \leq t < t_{IL2} \\ IL_n & if\ t_{IL2} \leq t < t_{ILn} \\ CL & if\ t > t_{ILn} \end{cases}$$

Stepwise change of the consumption level of the bottle cleaning machine
(maximum variation, average value and confidence interval (a=0.05) of 20 measurements)

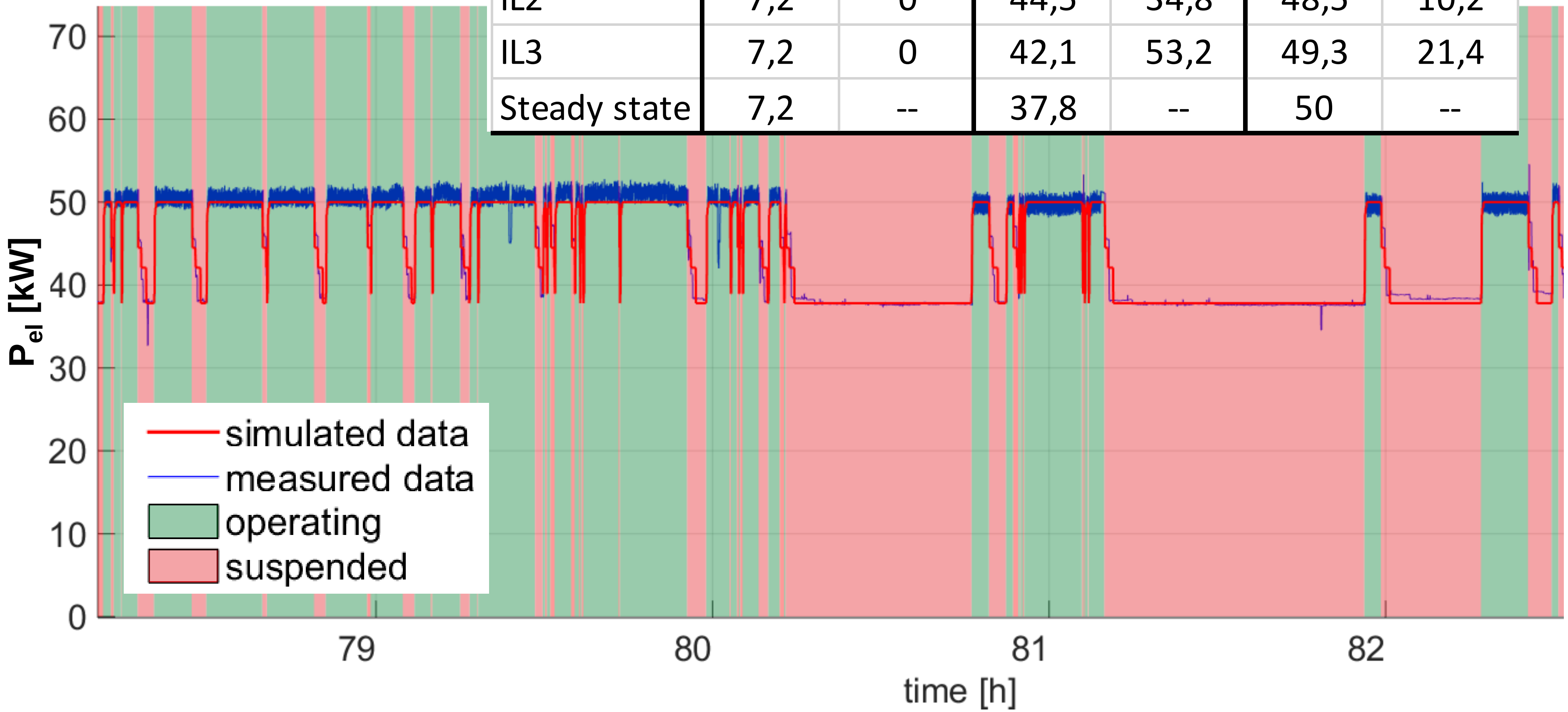
Model implementation



Model Validation for single machines

energy parameters for the bottle cleaning machine

	Incative		Suspended		Production	
	P [kW]	t [s]	P [kW]	t [s]	P [kW]	t [s]
IL1	7,2	0	49,78	4,9	38,9	4,5
IL2	7,2	0	44,5	34,8	48,5	10,2
IL3	7,2	0	42,1	53,2	49,3	21,4
Steady state	7,2	--	37,8	--	50	--

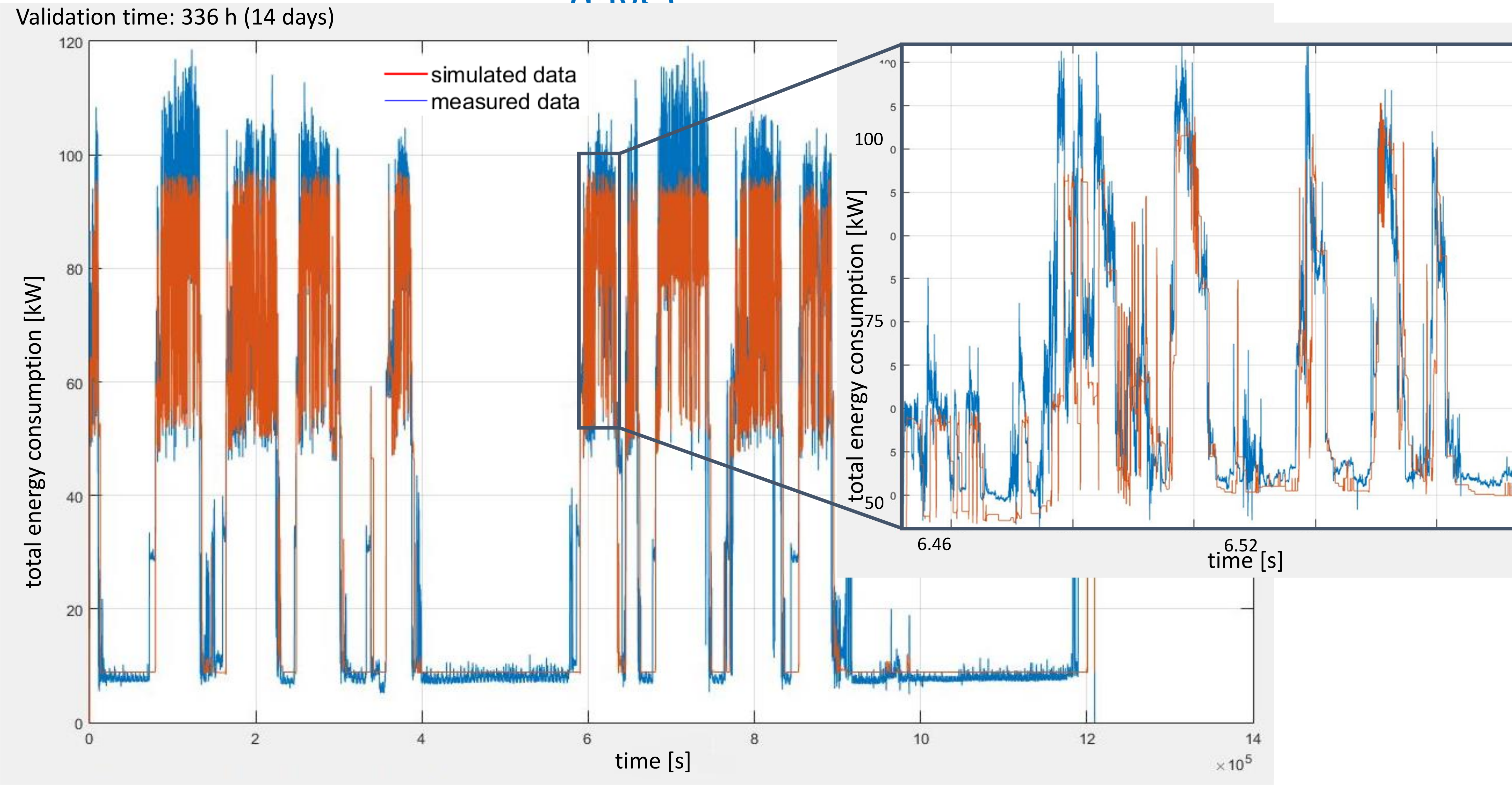


example of a validation plot for the bottle cleaning machine

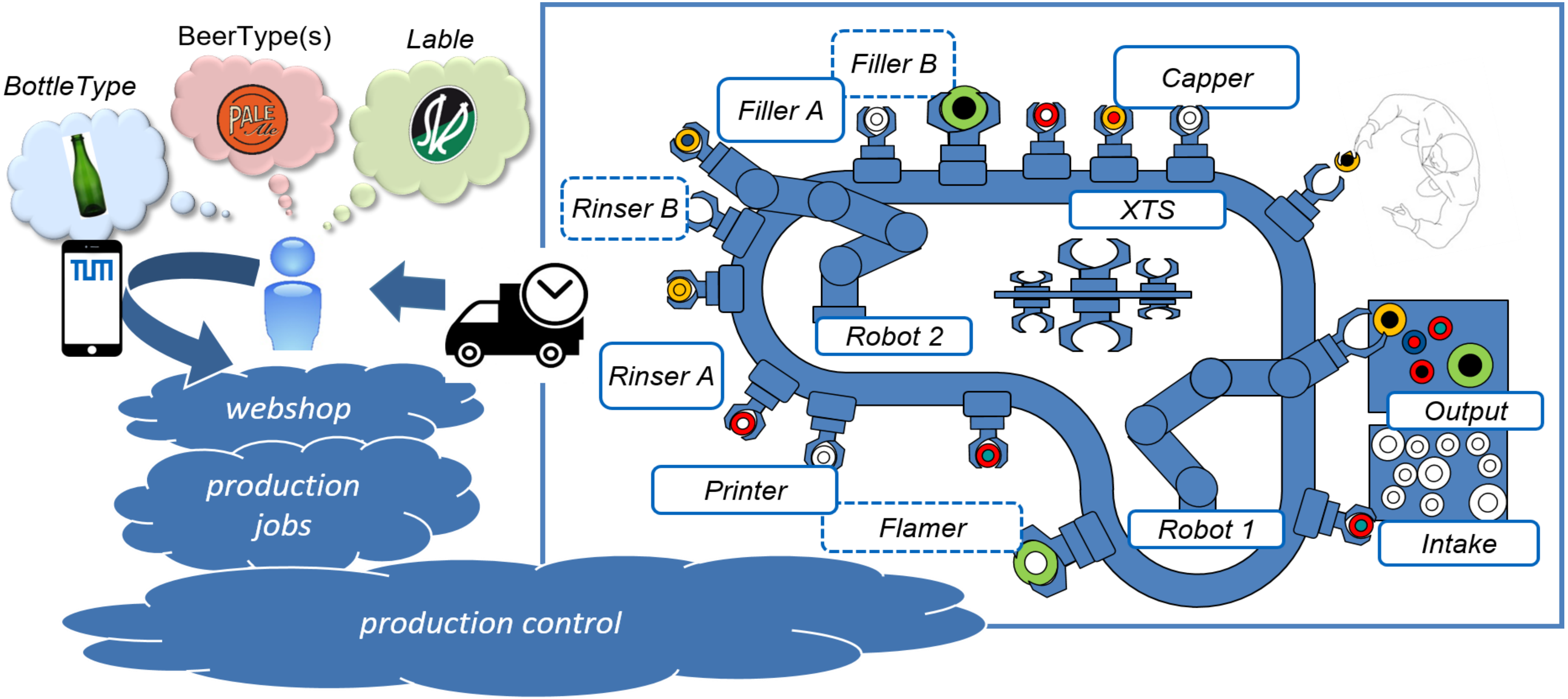
Summary of the validation results

	TIC	*APD*	*Measured*	*Simulated*	*Total deviation*	*credibility*	*acceptability*
Depalletizer	0.38	27%	418 kW	315 kW	-16%	0.05	no
Depacker	0.21	24%	356 kW	334 kW	-6%	0.48	no
Selective depacker	0,16	13%	305 kW	309 kW	1%	0,60	yes
Washing machine	0.16	32%	6007 kW	5910 kW	-2%	0.60	yes
Filler	0.11	17%	1541 kW	1528 kW	-1%	0.73	yes
Labeller	0.20	33%	392 kW	380 kW	-3%	0.50	yes
Packer	0.30	41%	403 kW	347 kW	-14%	0.25	no
Mixer	0,27	156%	1692 kWh	1805 kWh	7%	0,33	partially
Palletizer	0.29	28%	449 kW	431 kW	-4%	0.28	no
Crate Washer	0.15	16%	2670 kW	2492 kW	-7%	0.63	yes
Complete line	0.12	25%	14233 kW	13889 kW	-2%	0.70	yes

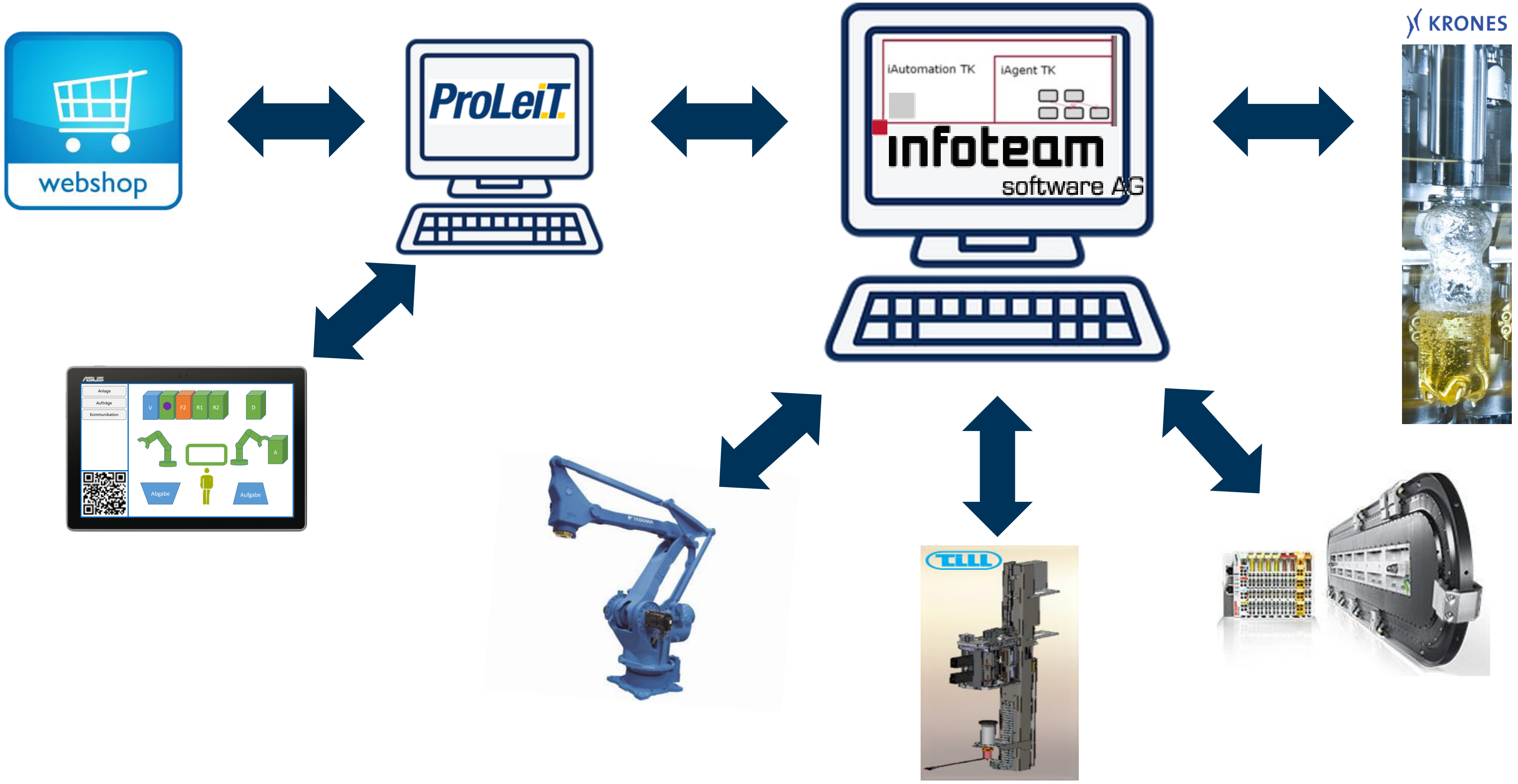
Validation plot of the complete bottling and packaging line (14 days)



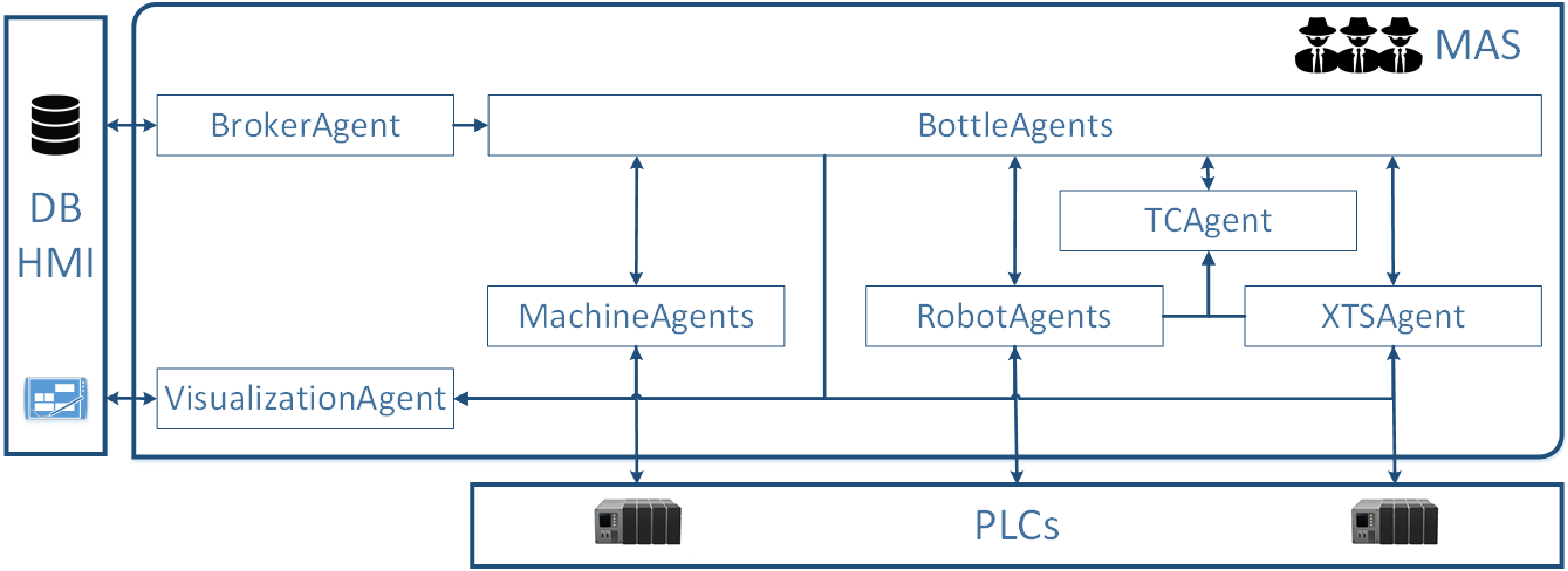
RoboFill - Agent-based bottling in lot size 1



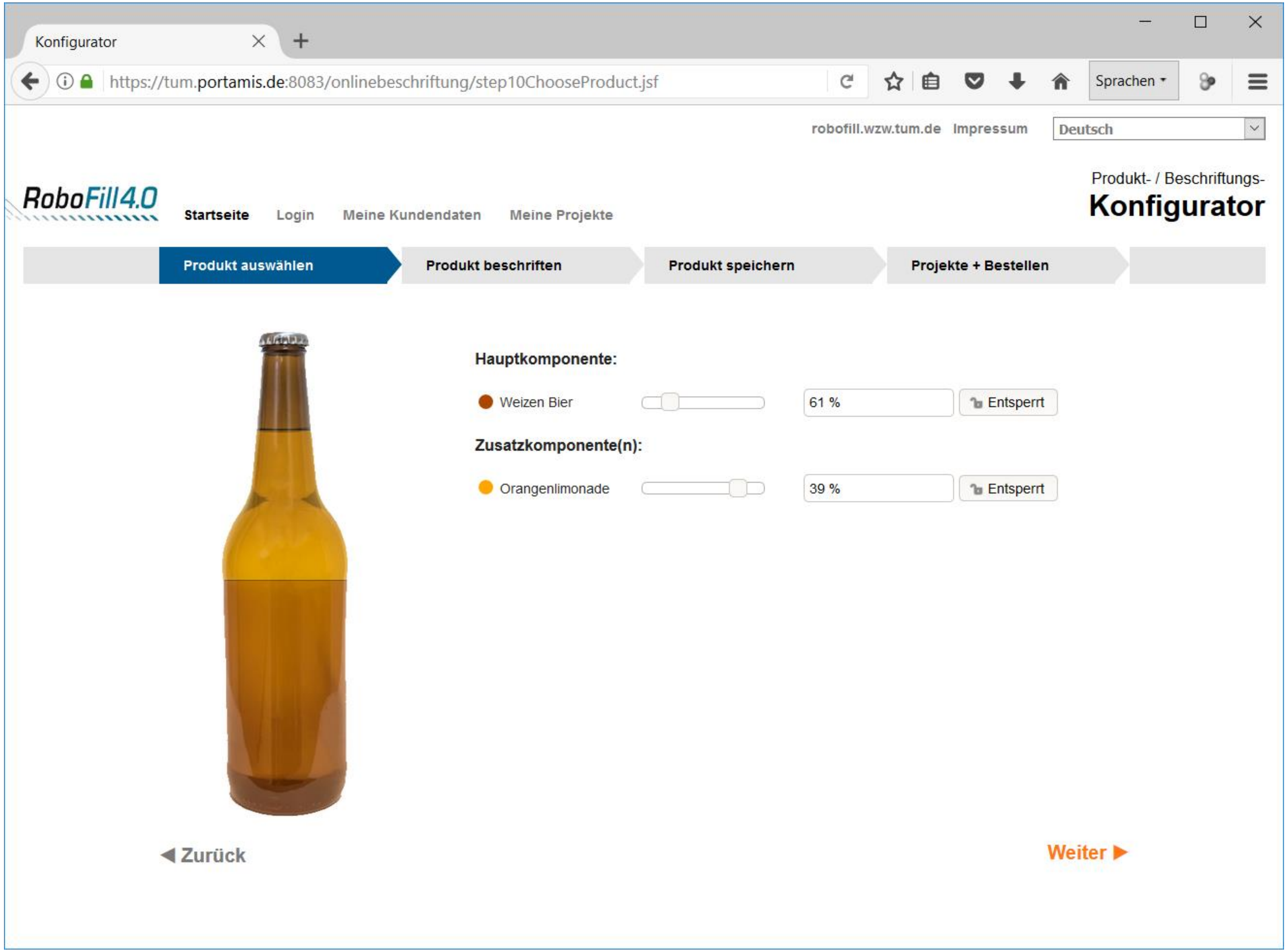
IT-Architecture of the cyber-physical production system



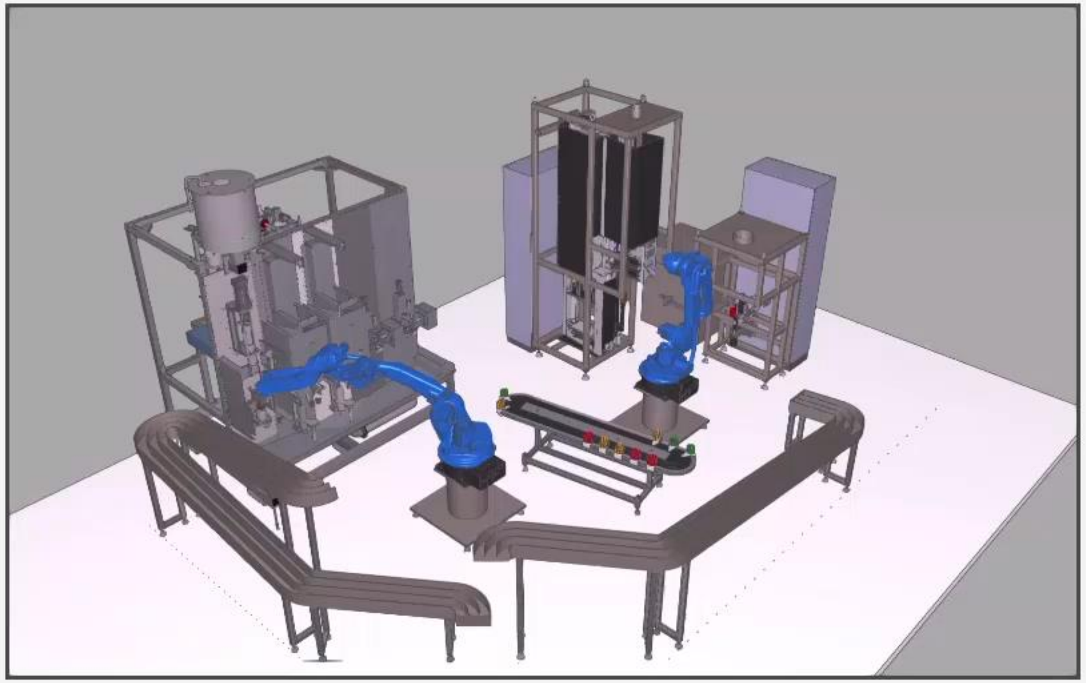
Agent System Architecture



Individualization in the RoboFill Webshop



Till Flamer	Till Printer	Yaskawa MH24 1	Beckhoff XTS	Yaskawa MH24 2	Krones Rinser 1	Krones Rinser 2	Krones Filler 1	Krones Filler 2	Krones Sealer
Available	Available	Ready	Available	Ready	Available	Available	Available	Available	Available



Digital transformation in the food industry

Chances

- cost reduction
  - ➢ increase in productivity
  - ➢ saving of resources
  - ➢ Improved production processes
- Stronger networking of the supply chain
  - ➢ Transparency and security
  - ➢ traceability
- Better product quality
  - ➢ Avoidance of food losses
  - ➢ Process stability with fluctuating raw materials
- Greater flexibility
  - ➢ Increasing the reaction speed
  - ➢ More customized products

Challenges

- Consistent internal and external digital networking
  - ➢ (Standardized) communication interfaces
  - ➢ Big data sharing
- Reusable product and process models (Digital Twins) for
  - ➢ Product development and plant planning
  - ➢ Virtual commissioning
  - ➢ production control
- Reference applications in the food industry
  - ➢ Decentralized production control (agents)
  - ➢ Machine Learning (Analytics)
  - ➢ Digital business models