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INDUSTRY 4.0 AND DIGITALIZATION IN THE PLASTICS INDUSTRY

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IWK Institute for Materials Technology and Plastics Processing, Eastern Switzerland UAS

#ANTEC24

AGENDA

- IWK: Who we are
- The challenges of digitalization
- First step: Definition of use cases
- Digitalization in injection moulding production
- End-to-end digital product lifecycle management (PLM)
- Potential in compounding and extrusion
- Conclusions

IWK @ EASTERN SWITZERLAND UAS

founded in 2005

53 Staff

8 Research Fields

IWK @ EASTERN SWITZERLAND UAS

Plastics Processing

Prof. Daniel Schwendemann
Dep. Head of Institute

Research Field
Compounding / Extrusion

Prof. Dr. Gion A. Barandun

Research Field
Composites/ Light Weight Construction

Dr. Daniel Omidvarkajan

Research Field
3D Printing / Additive Manufacturing

Curdin Wick

Research Field
Injection Moulding / PUR

Cross-cutting Topics

Prof. Dr. Markus Henne

Research Field
Mechanical Systems

Prof. Dr. Samuel Affolter

Material Analysis / Failure Analysis

Prof. Dr. Mario Studer

Research Field
Design and Simulation

Prof. Dr. Pierre Jousset

Research Field
Joining Technology

Metal Processing

Prof. Dr. Mohammad Rabiey

Research Field
Metal processing

Prof. Dr. Frank Ehrig

Head of Institute

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THE CHALLENGES OF DIGITALIZATION

Demands on the companies

- The energy crisis and the **careful use of resources** reinforce the **need for zero-defect production.** The resulting enormous **cost pressure** and the demand for continuous **quality monitoring** pose new challenges for injection molding processors.
- **Process monitoring** and **quality prediction** and control play a decisive role when it comes to Industry 4.0 in injection molding companies.
- In the context of **digitalization**, there are **many interesting use cases** designed to optimize injection molding as a production process.

THE CHALLENGES OF DIGITALIZATION

There are two main challenges in implementing

1. There is a **lack of awareness** in practice, both **for possible applications and for the necessity of an implementation**.
   - How can I increase my value creation by using data?
   - How can I use my data? What is the goal?
   - What data do I need to implement a specific use case?

2. Learning from data requires a **complete data base**. Some questions arise here as well:
   - Which signals do I need? Which signals are available at all?
   - What quality of data do I need? Is the data available in this required quality?
   - How do I get the data out of my machine?
   - How do I synchronize data from different machines and devices?

Standardized interfaces / communication protocols offer a possibility for "simpler" data export, but also have limitations

OPC UA

EUROMAP
European Plastics and Rubber Machinery

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THE CHALLENGES OF DIGITALIZATION

"AI"-based research projects at the IWK

Require-ments → Material selection → Part design → Process design → Tool manufact. → Sampling → Production

- PLM
- Virtual-DoE
- Extrusion Tooling
- Unique Part Identification
- Anomaly Detection
- Predictive Maintanance
- Predictive Quality

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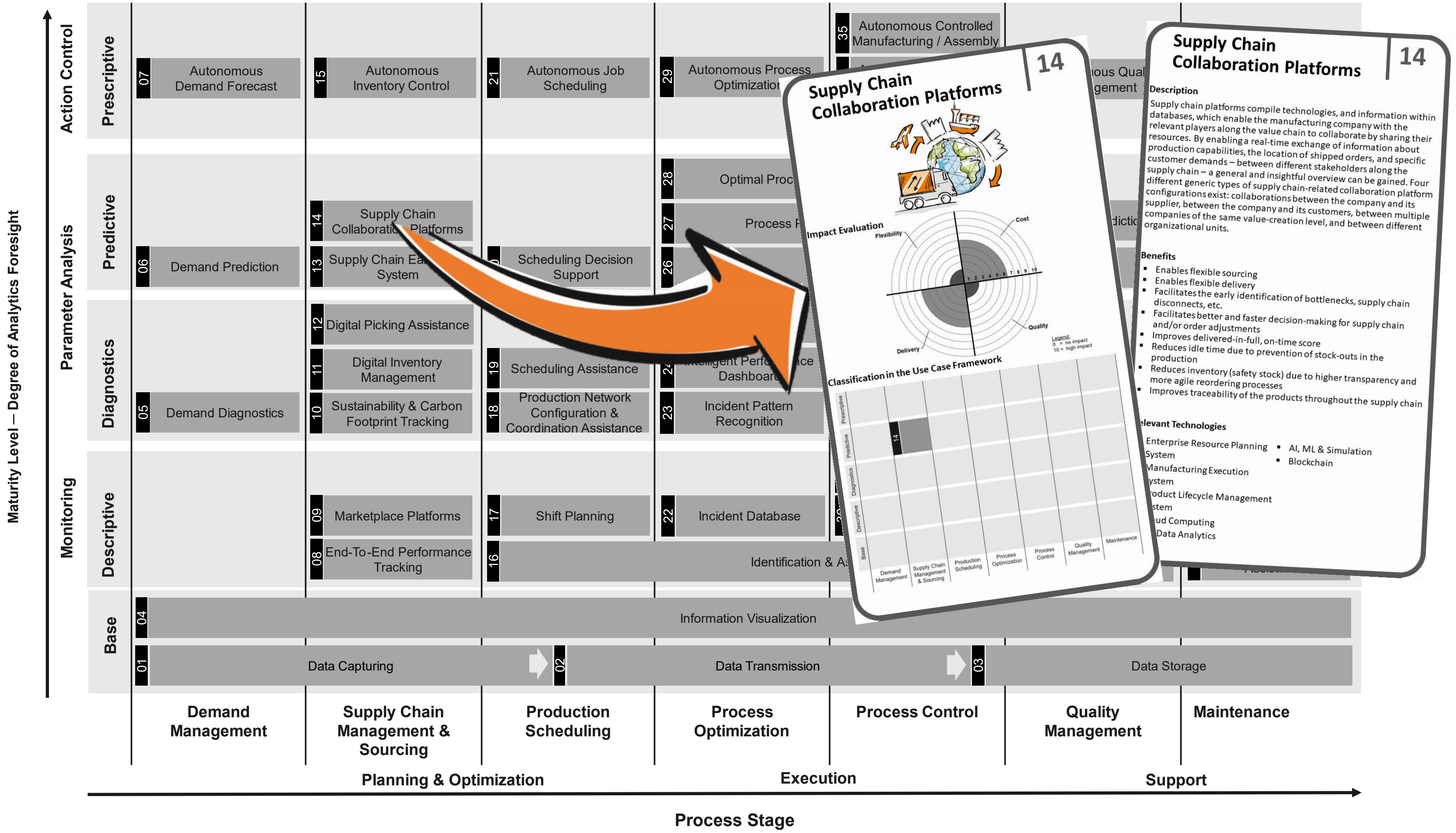
FIRST STEP: DEFINITION OF USE CASES

Use Case Orientation – Key to success – Result Orientation



*Source: Smart Factory Navigator , Lukas Budde, **Roman Hänggi**, Thomas Friedli, Adrian Rüedy, Springer (2023) ISBN 978-3031172533*

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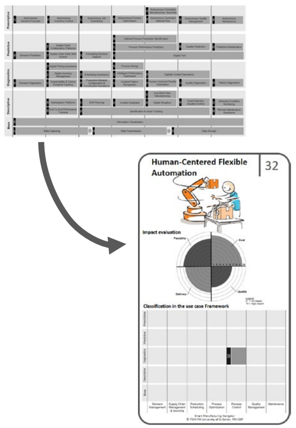
FIRST STEP: DEFINITION OF USE CASES

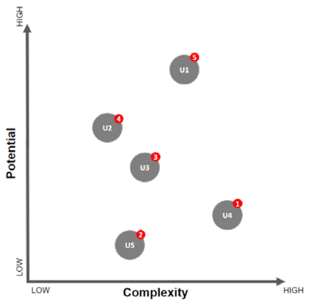
Smart Factory Implementation Process

1. Selection of promising use cases



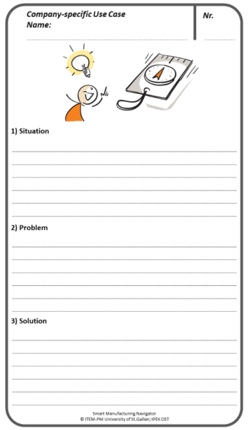
Derive use cases from the framework and select the best fitting ones

2. Classification in potential and complexity



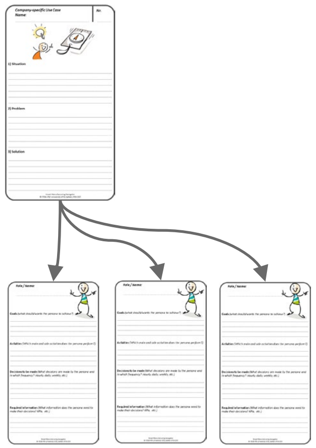
Categorization of the use cases in regard to future potential and implementation complexity

3. Adaption of the use cases to a company-specific context



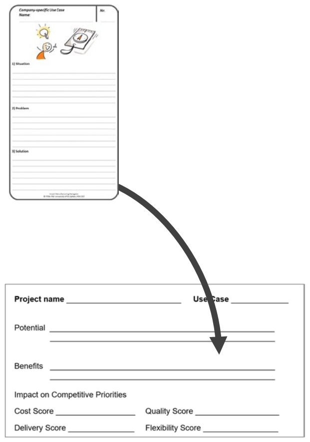
Adaptation to individual firm-specific characteristics and strategic cross-check

4. Creation of personas for each use case



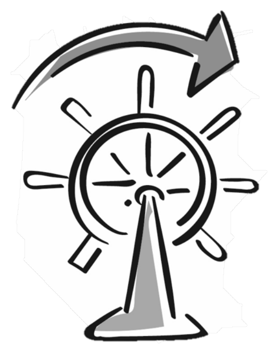
Identification of affected stakeholder groups

5. Project setup



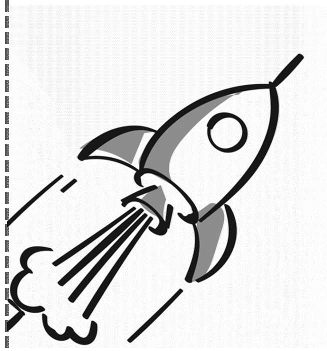
Further specification to gain insights

6. Implementation



Implementation of the elaborated project under consideration of the relevant stakeholder

7. Scaling and internationalization



Iterative process approach, scaling

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Anomaly detection system for the injection molding process

29 Autonomous Process Optimization

Goal

- Development of a machine learning-based process management system to optimize the injection molding process

Results

- ML algorithms for the early detection of anomalies and recommendations for countermeasures

Partners

- ICOM and IPEK (OST)
- Kistler, KraussMaffei, Geberit, Weidmann, Netstal

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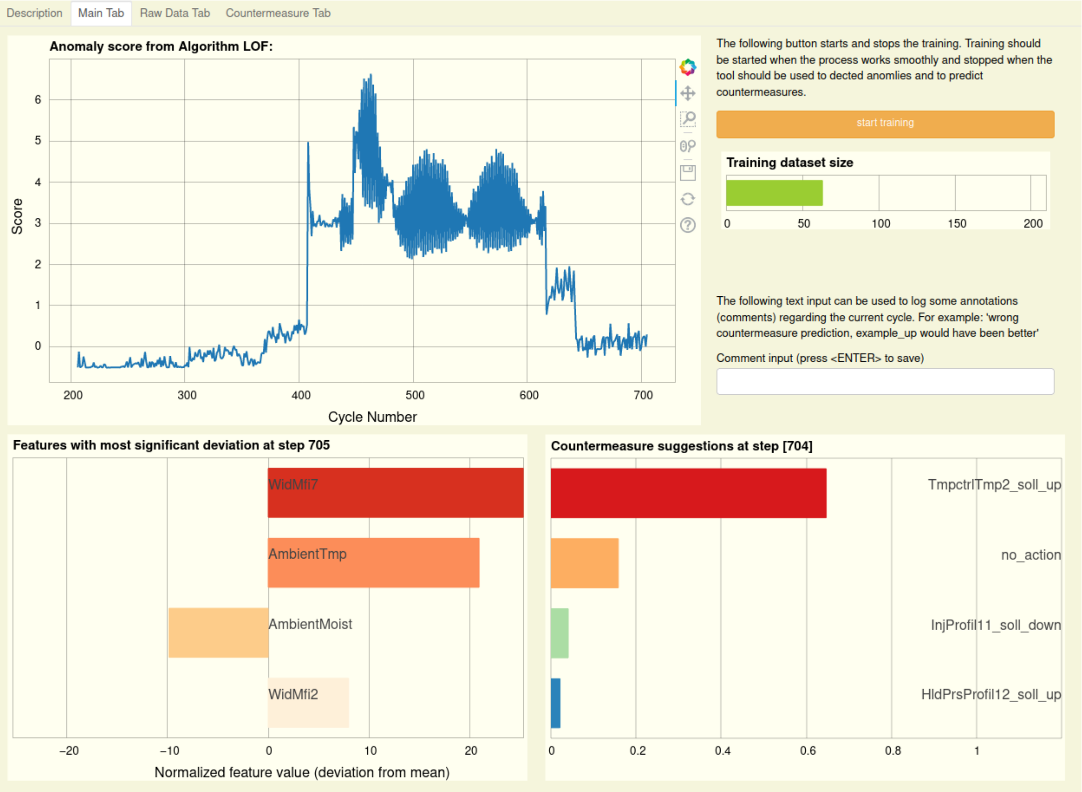

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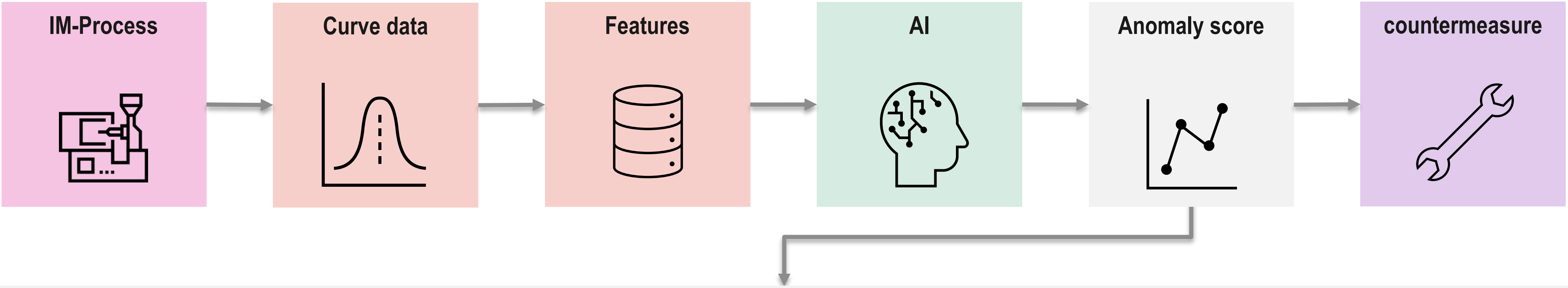
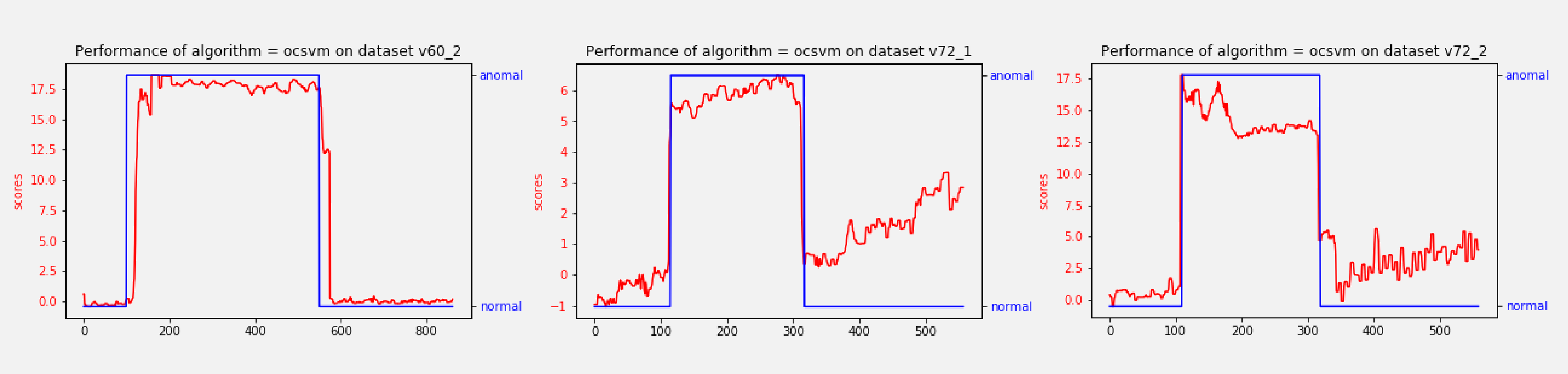
Anomaly detection system approach

29 Autonomous Process Optimization





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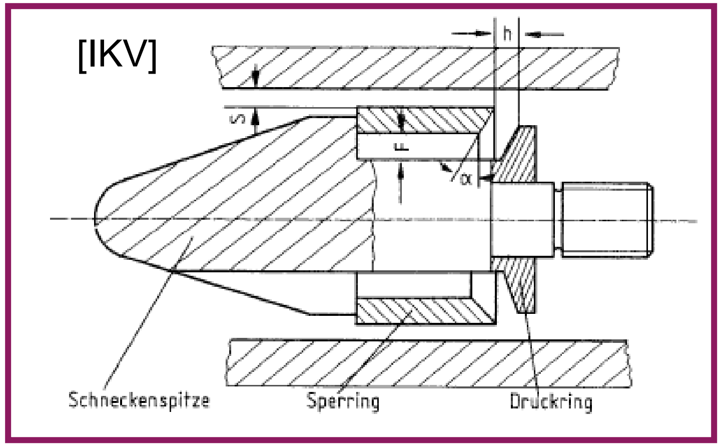
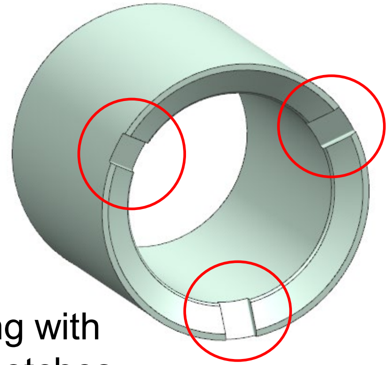
43 Predictive Maintenance

Predictive maintenance: Defect non-return valve

- A well-known anomaly in the injection moulding process is the wear of non-return valve
  - To simulate this anomaly the ring of a non-return valve was artificially damaged, means notches with different depths were milled
- 5 test series, part: ice scraper, material: ASA
  - Trial series 1 – intact non-return valve
  - Trial series 2 – damaged non-returned valve, notch depth 0,33 mm
  - Trial series 3 – damaged non-returned valve, notch depth 0,67 mm
  - Trial series 4 – damaged non-returned valve, notch depth 1,00 mm
  - Trial series 5 – damaged non-returned valve, notch depth 0,20 mm
- Database
  - Process curves recorded with the DataXplorer, Krauss Maffei

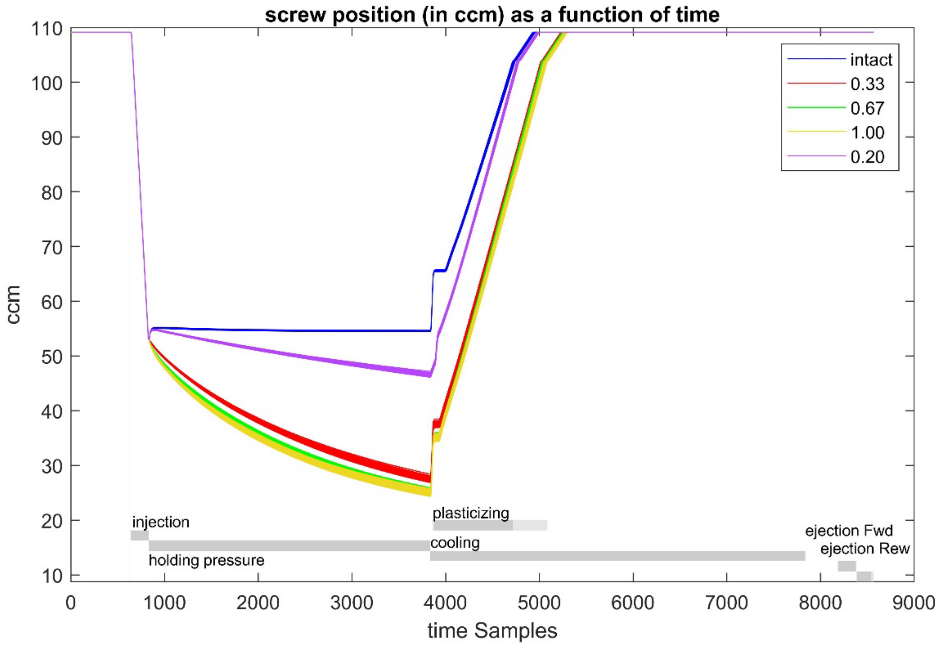


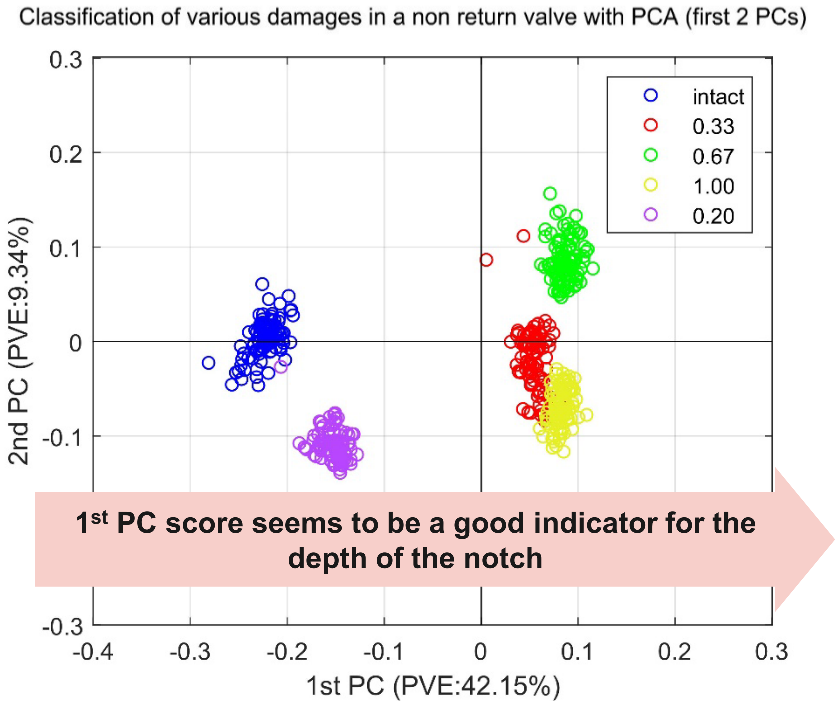


Locking ring with machined notches

Predictive maintenance: classification of trial series

- With damaged non-return valves, the screw covers significantly longer distances during holding pressure phase, scattering increases with higher wear → already known in industry



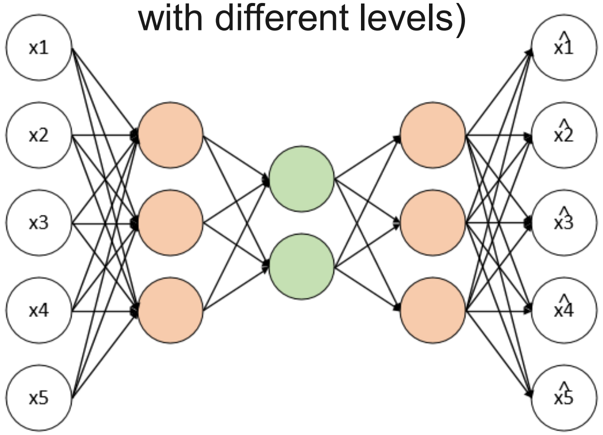


Predictive maintenance: Use of an auto encoder

43 Predictive Maintenance

- Can ML detect these anomalies even before the machine operator and determine the time for a replacement?
  - Results of additional trials with an unhardened non-return valve and high reinforced PPA material:

Auto encoder (neural network with different levels)



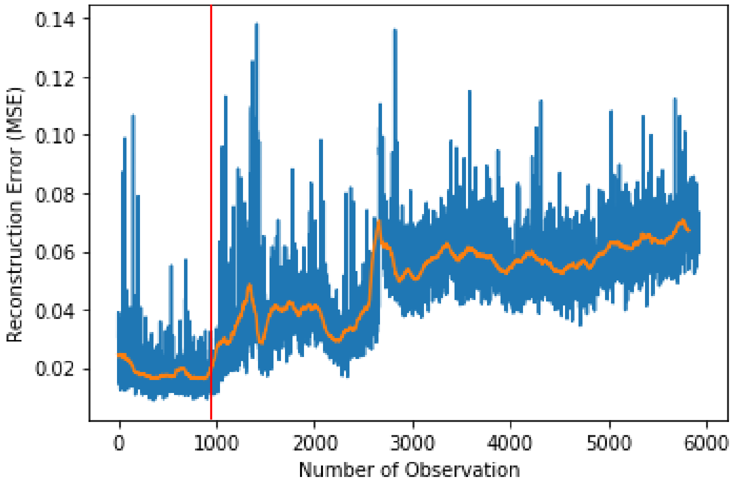
features

recalculated features

Reconstruction error calculation with RMS

$$f_{rms} = \sqrt{\frac{1}{n}\sum_{k=1}^{n}((\widehat{x_k} - x_k)^2)}$$

Reconstruction error in function of cycle number



Predictive maintenance: Use of an auto encoder

43 Predictive Maintenance

- Can ML detect these anomalies even before the machine operator and determine the time for a replacement?
  - Results of additional trials with an unhardened non-return valve and high reinforced PPA material:

Identification of anomalies

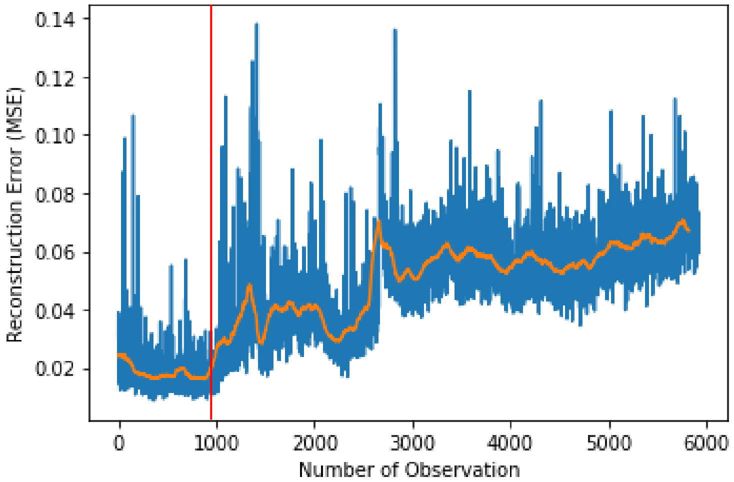
reconstruction error ↑

Index	0_caller	1	2	3	4
64	11.9467	13.4402	19.2116	18.4646	16.2018
68	12.3311	13.7234	18.4835	17.8316	15.9617
195	9.8003	11.2507	14.3728	14.0198	12.7106
191	9.70302	11.2043	14.3134	13.6768	12.5816
85	6.73853	7.81164	11.6803	10.2961	10.9288

number of cycles →

1. minimal screw position = melt cushion
2. variance screw position

Reconstruction error in function of cycle number



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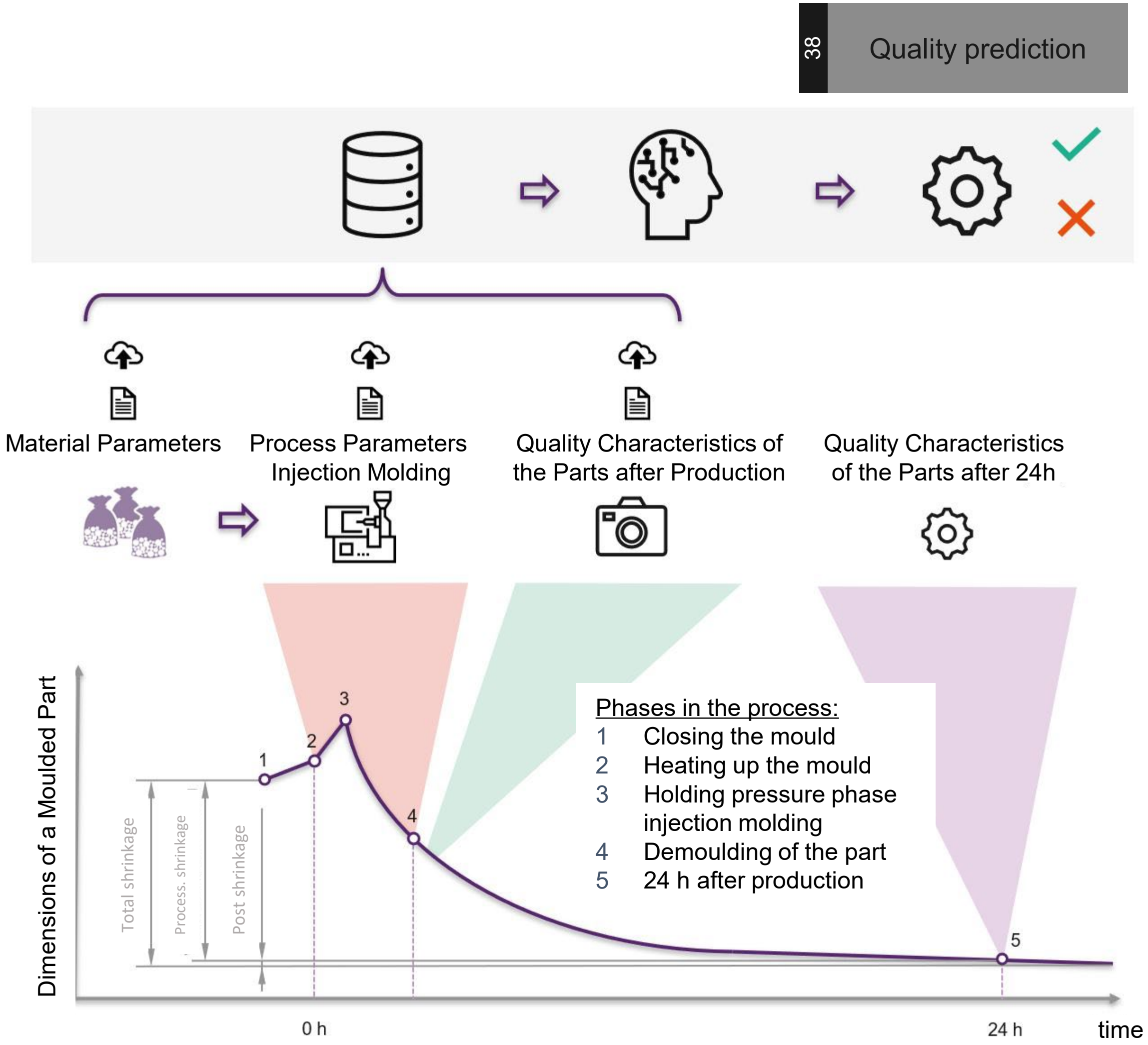
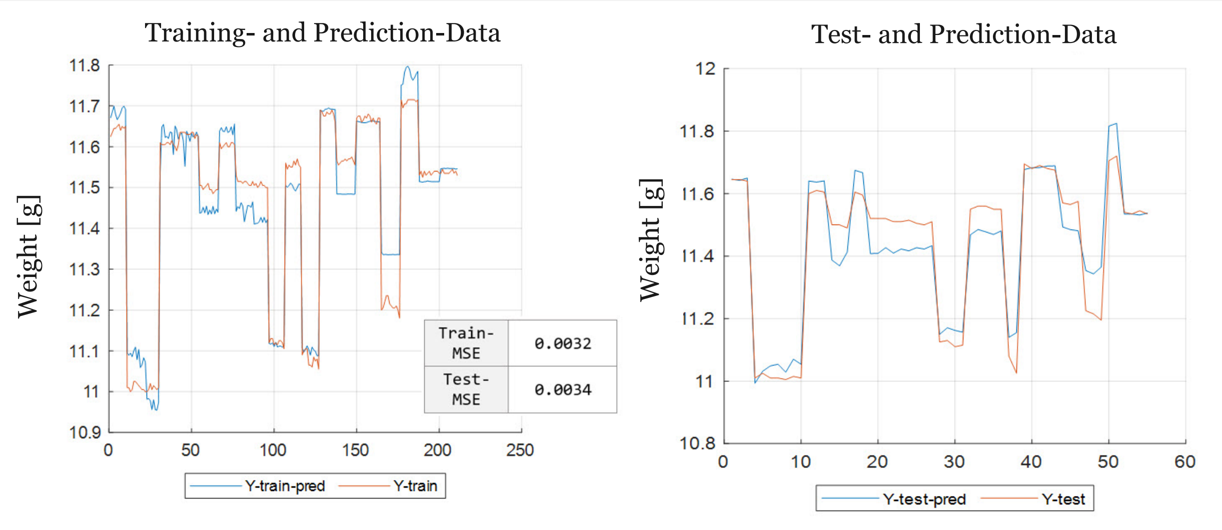
Quality Predicition

- Quality characteristics: Measuring effort should not be underestimated
- The dimensional accuracy of the parts can only be determined 24 hours after production.
- Including of measurements directly after production can improve the accuracy



Floorball: Results

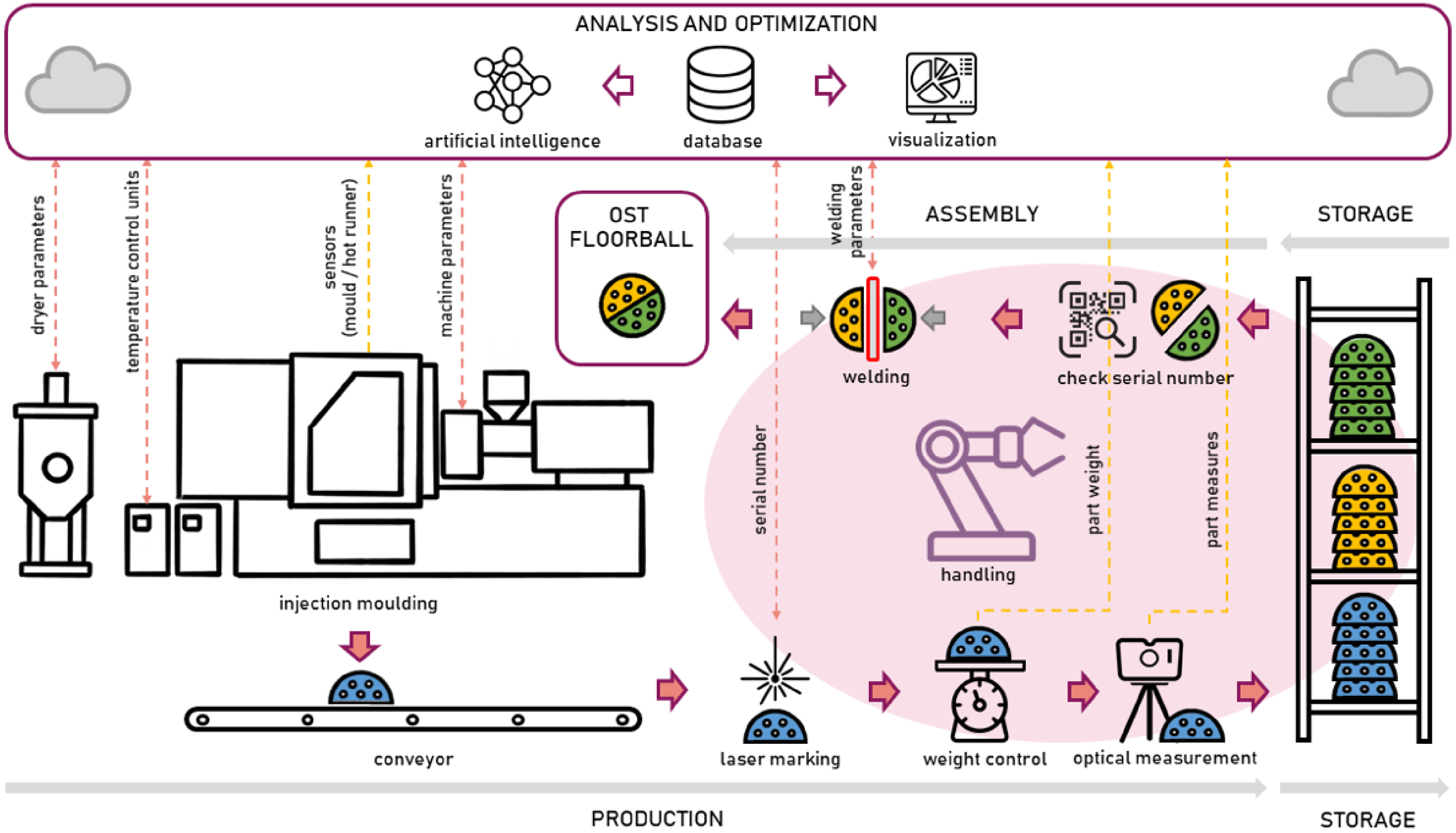
- Prediction of the part weight
- Already with a simple linear model a R^2 of approx. 0.85 can be achieved
- The model is improved by adding interaction terms, which allows a R^2 greater than 0.9.



Training- and Test-Data (random split 80% / 20%) with Stepwiselm regression.

Build-up of a Smart Factory@OST

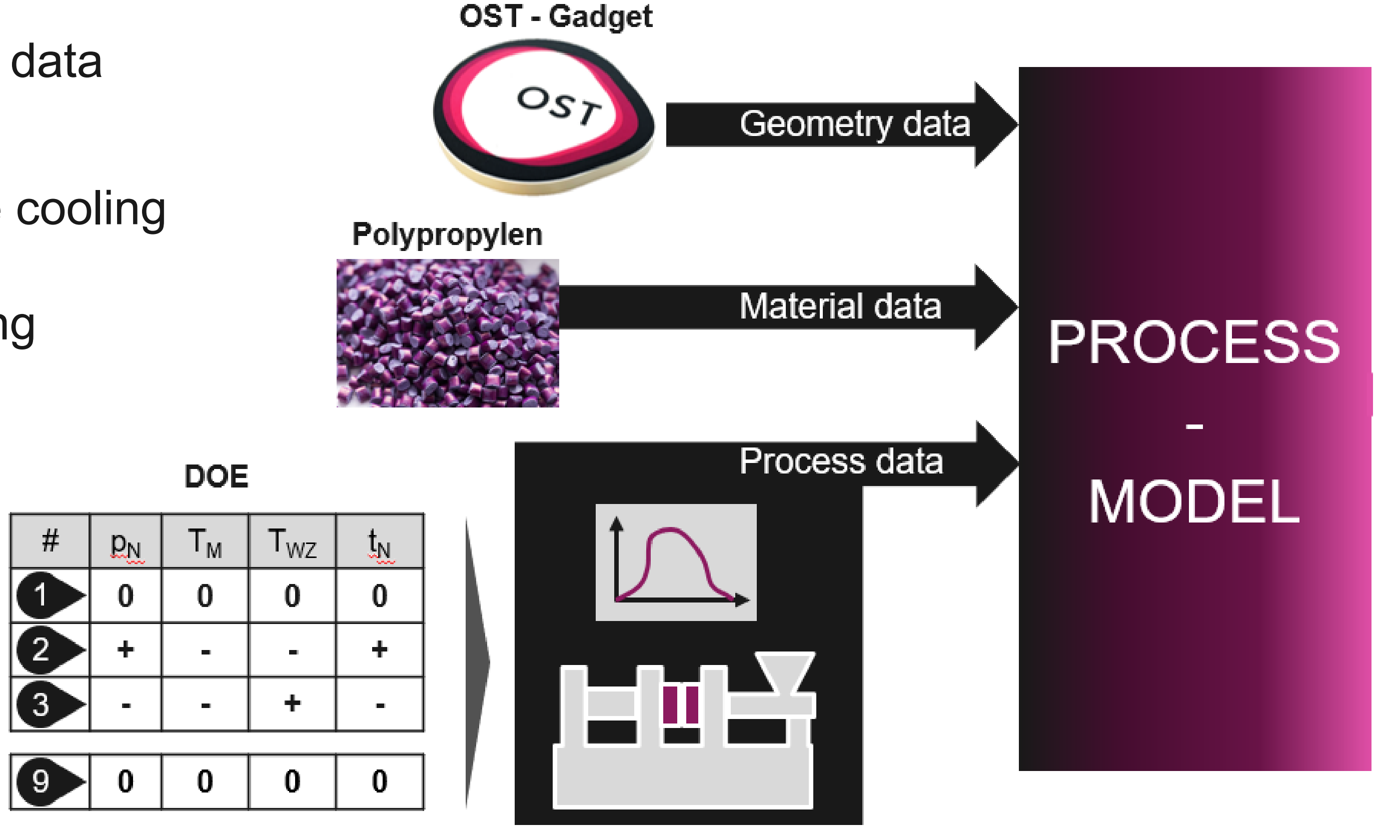
38 Quality prediction



Physical model approaches to reduce test effort

38 Quality prediction

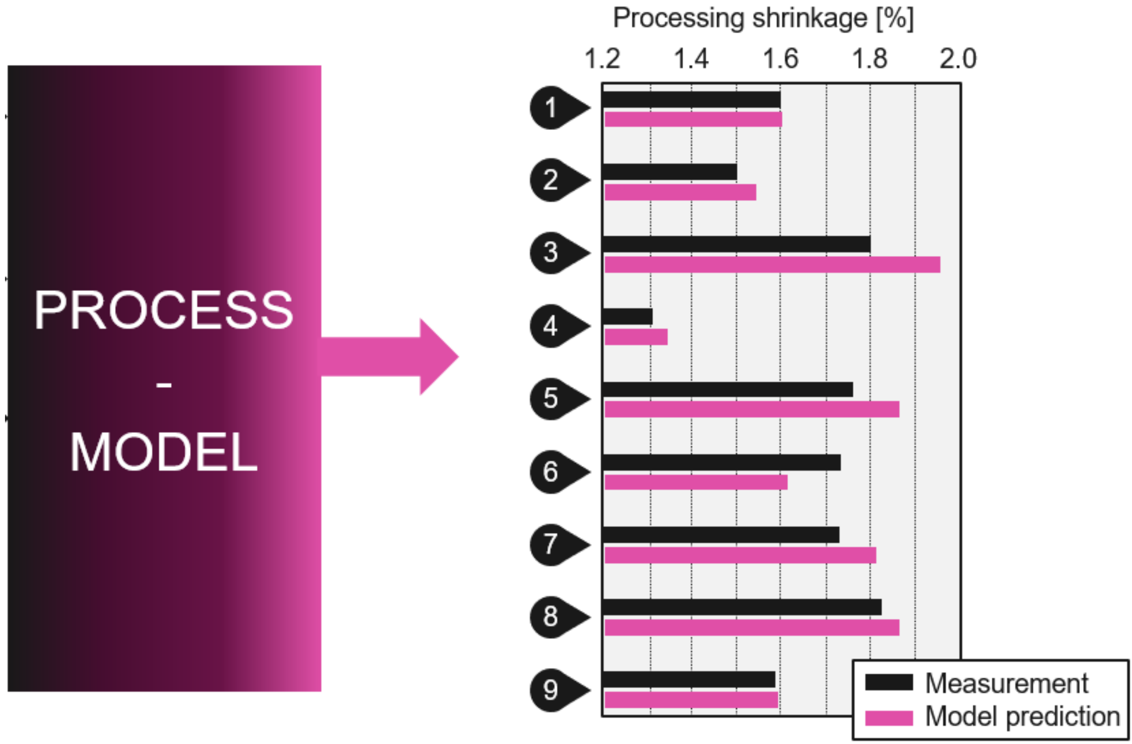
- The next step is to physically represent part shrinkage
- Combination of process data and material data (pvT data, thermal data)
- A **simplified numerical simulation** of the cooling process and associated density changes determines the process-induced processing shrinkage (almost real time simulation)



#	p_N	T_M	T_{WZ}	t_N
1	0	0	0	0
2	+	-	-	+
3	-	-	+	-
9	0	0	0	0

Initial Validation Test with the OST Gadget

- Classic Design of Experiment, systematically varying shrinkage-relevant process settings
- Intital model validation using processing point 1
- Material PP
- Length and width of a housing cover were measured to determine the processing shrinkage based on the actual mass of the tool.
- Comparison between experimentally determined shrinkage values and predicted values showed a qualitatively good correlation across all process points.



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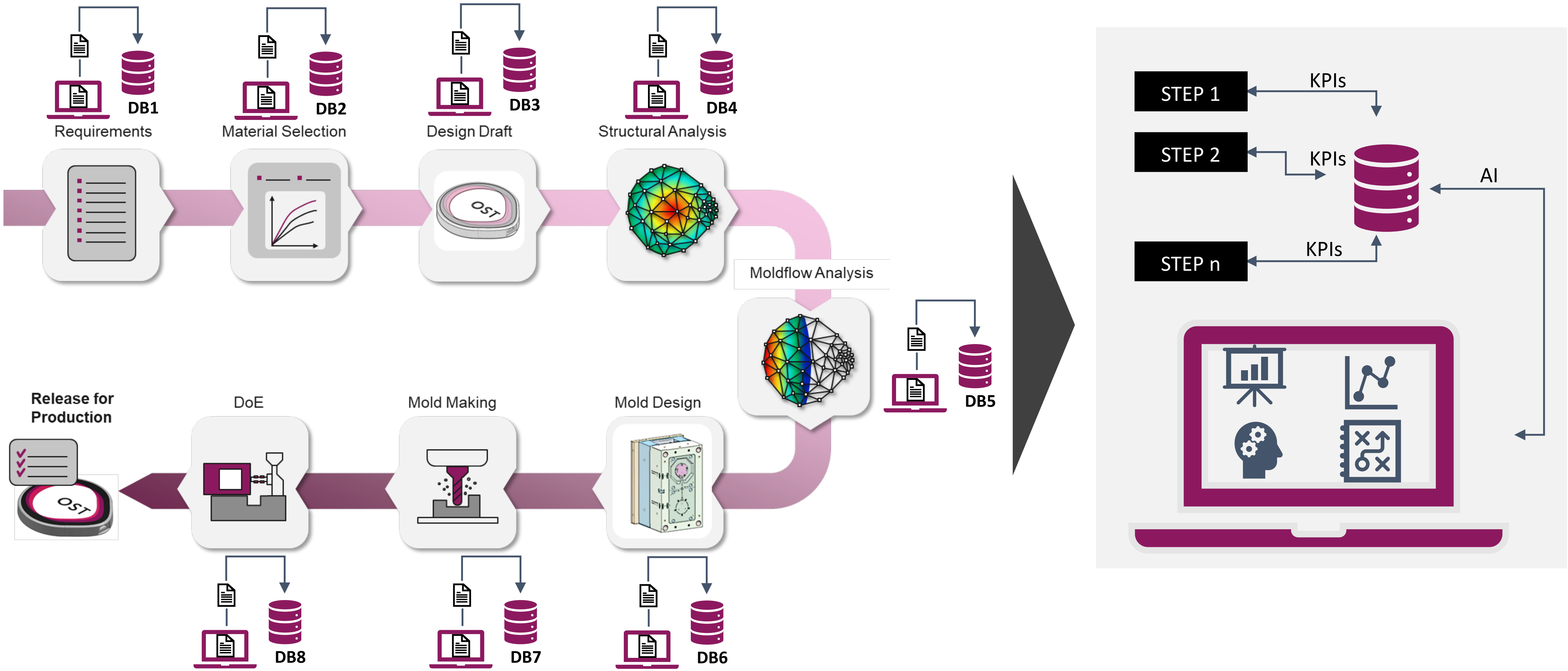
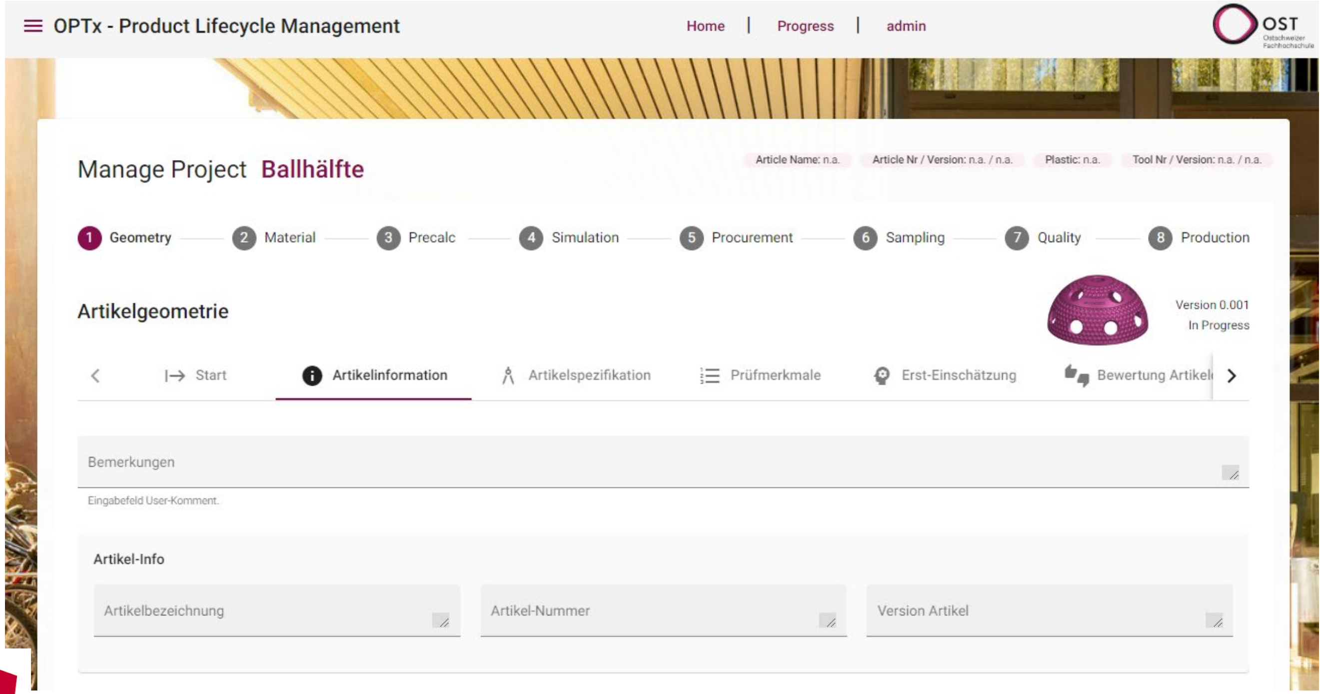
END-TO-END DIGITAL PRODUCT LIFECYCLE MANAGEMENT (PLM)

Idea: Making all data available



END-TO-END DIGITAL PRODUCT LIFECYCLE MANAGEMENT (PLM)

Development of a software prototype



- Browser and mobile-capable modern software with DB connection
- Digitization of the entire process chain and development history
- Comprehensive knowledge management (processes, materials, ...)
- "Arbitrarily" scalable or expandable

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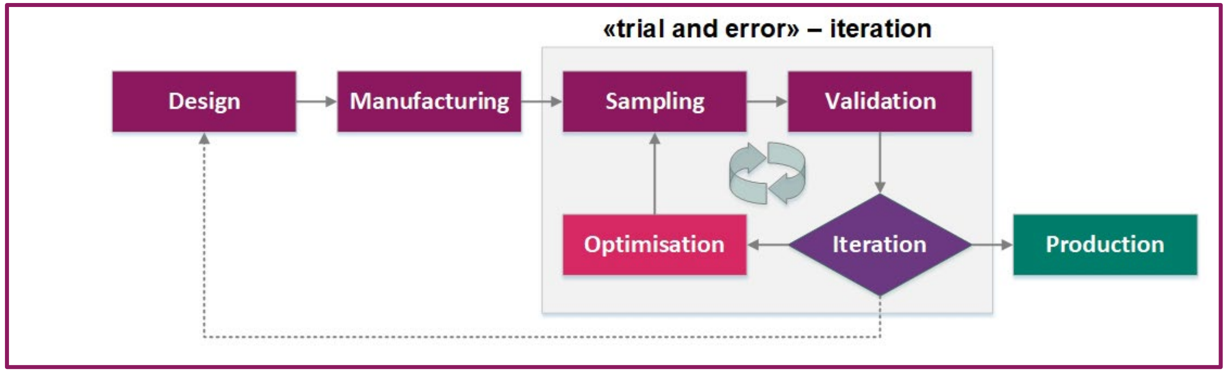
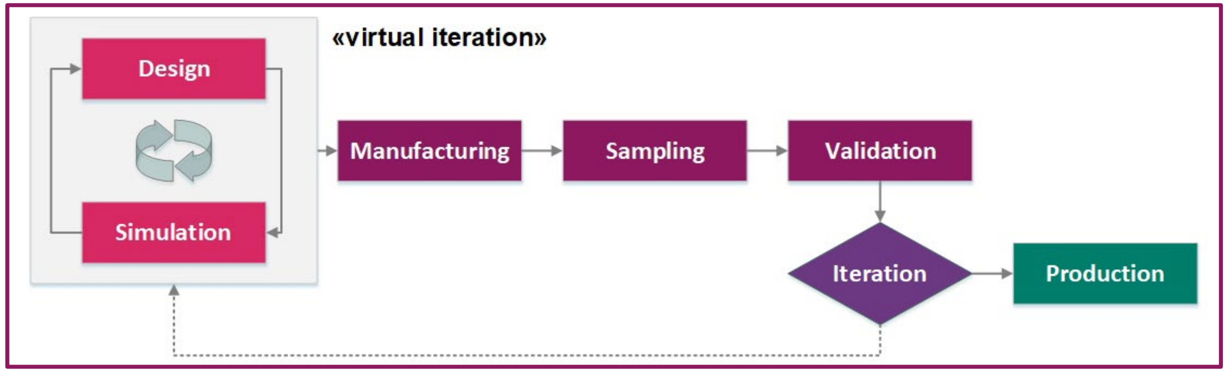
Objective: Faster extrusion die tooling

Digital twin

- Transfer tool and process development for profile extrusion from «trial and error» to «virtual iteration».
- The achieved profile geometry, including shrinkage and warpage, can be virtually reproduced.
- Using rapid CAD design with automated features developed at ETH, Zürich

pd|z ETH zürich

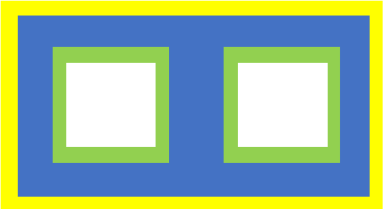




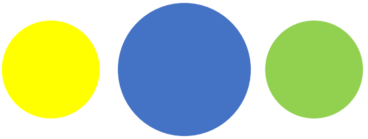
Steps to an extrusion die: Cooperation with ETH, Zürich

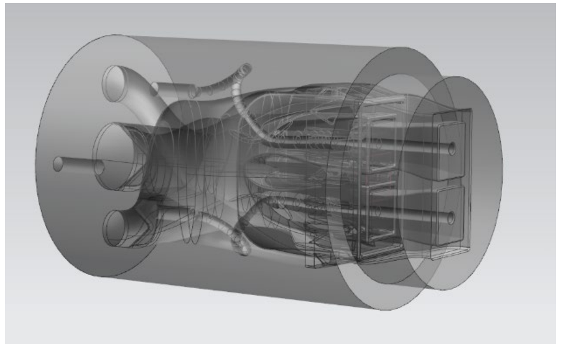
Requirements for nozzle → **Rapid CAD design with automated features** ⇄ (**Automation**) **Single and multi-flow CFD / FEA analysis** → **Additive manufacturing in steel and post-processing**

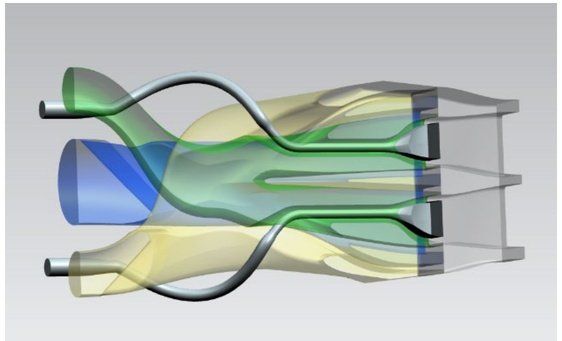
Target profile



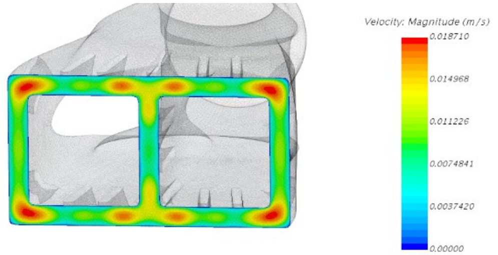
Nozzle inlets



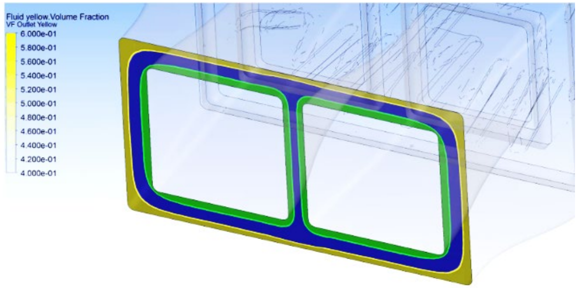


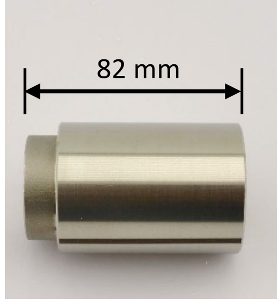


Simulation of each flow distributor



Detailed analysis at conjunction





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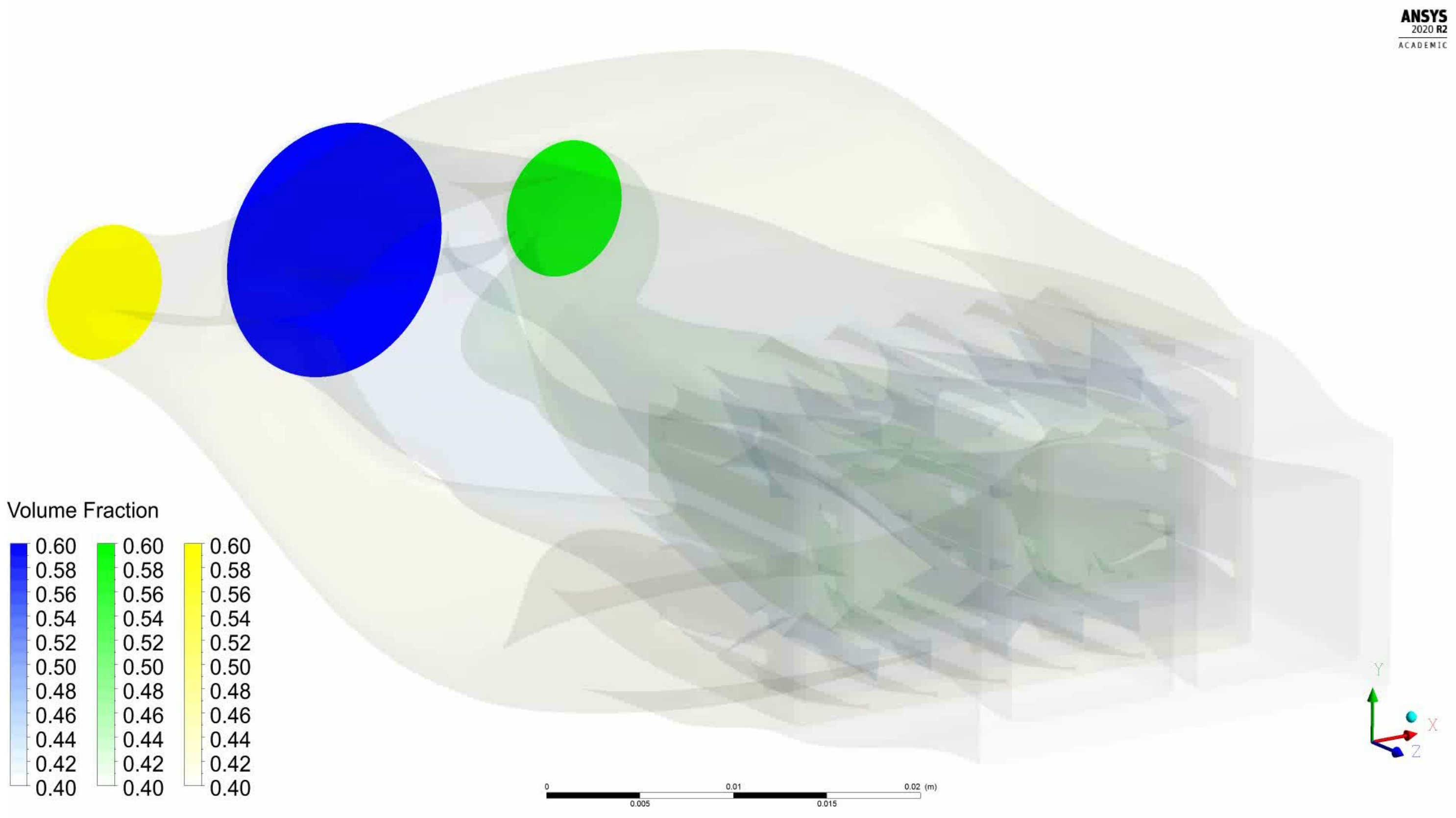
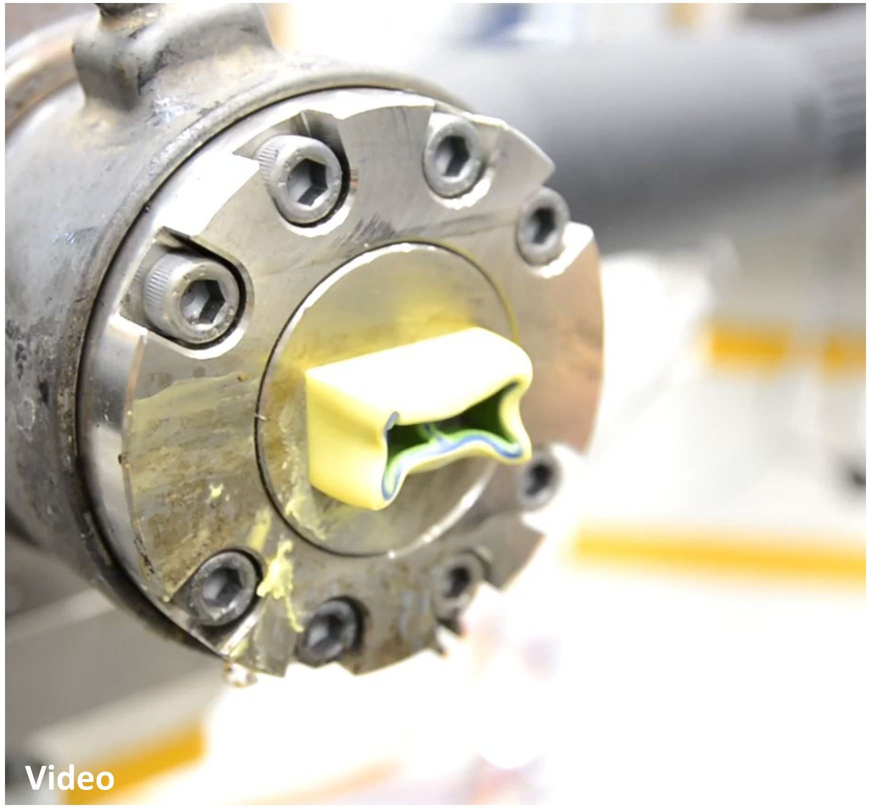
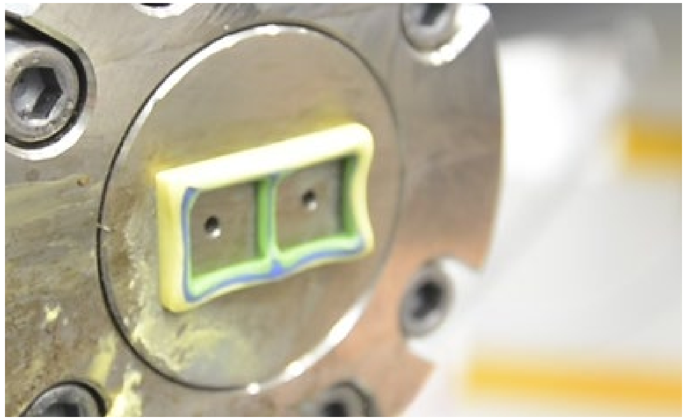
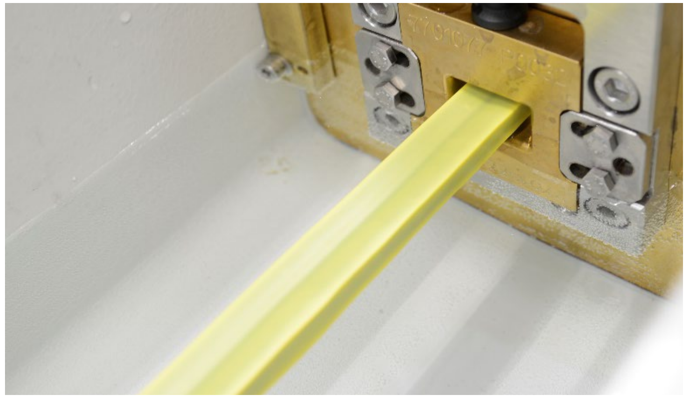


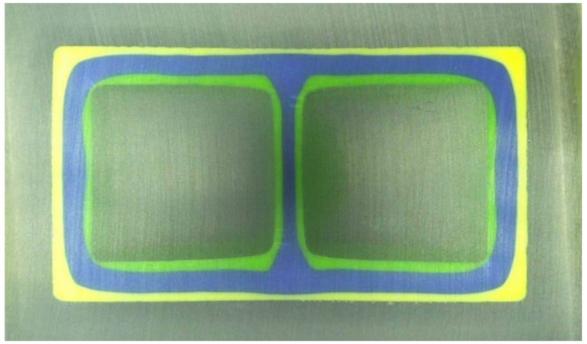
Tests results for co-extrusion of high impact Polystyrene



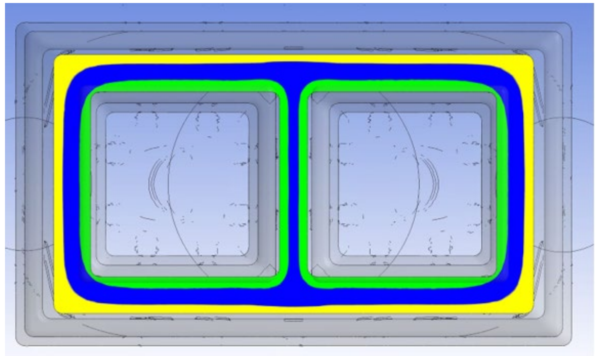




Test result (grinding pattern)

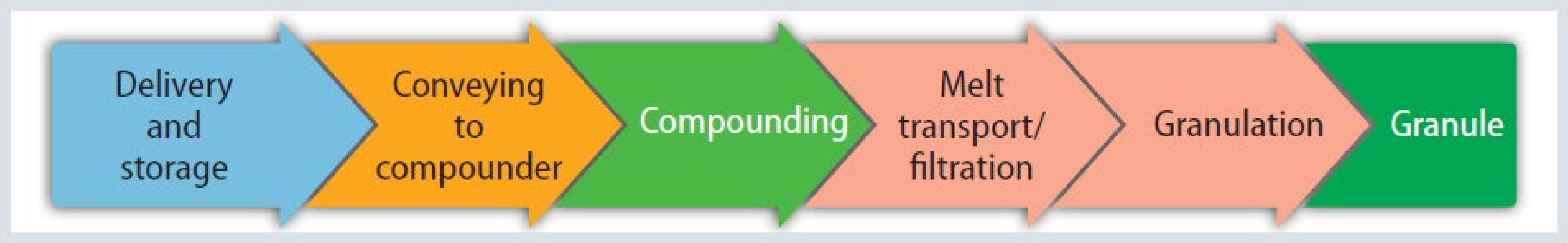


Simulation of co-extrusion



The challenge of data acquisition during compounding

- Compounding is a continuous process: Date can't be assigned to a single part. But continuously recorded and then assigned to different batches
- Main process steps are shown below. Each step provides important information for the process

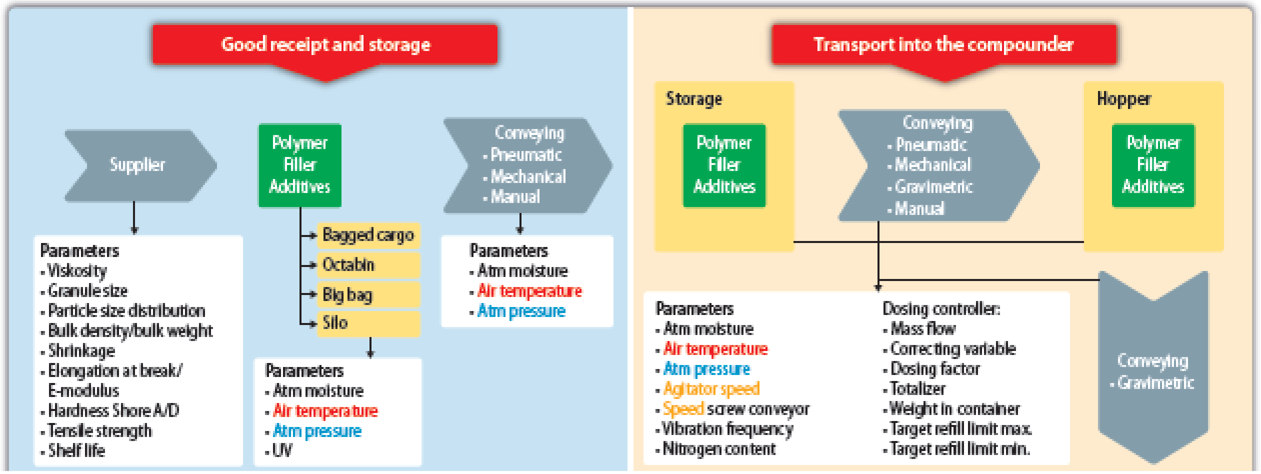


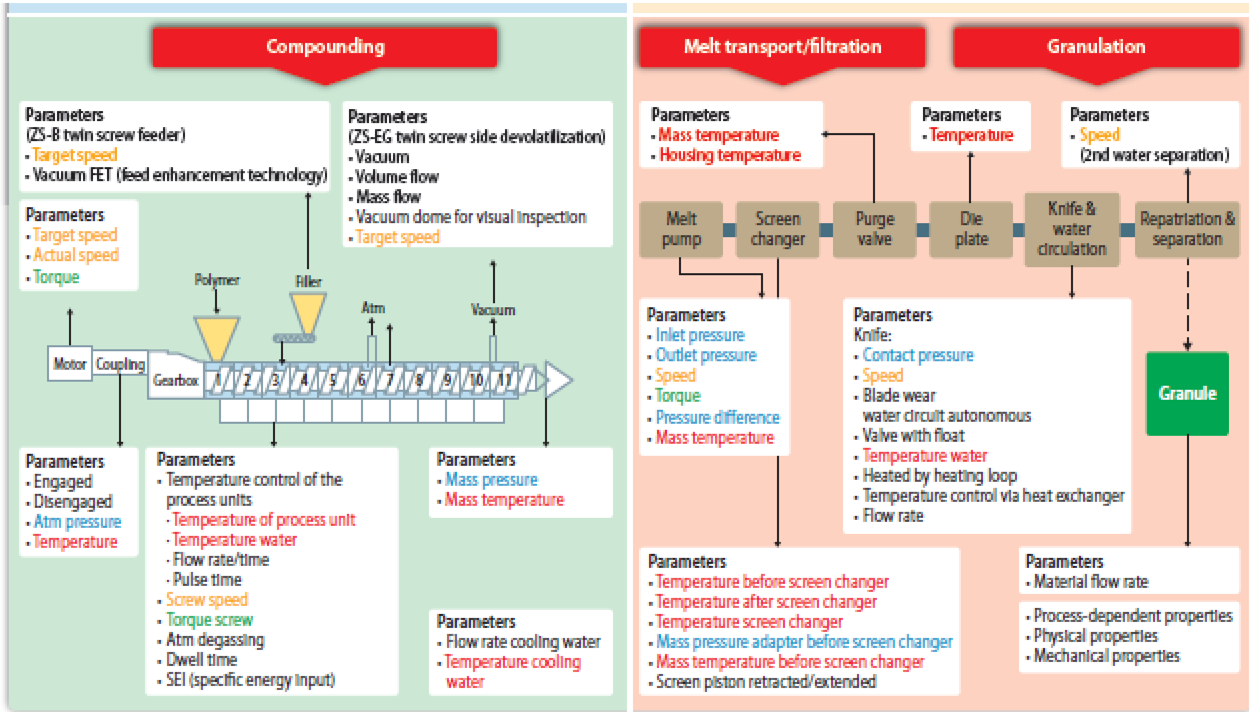
Source: OST; graphic: © Hanser

- The aim is now to record and evaluate this information from the compounder and its peripheral devices as well as other sensors.
- A central data acquisition system will be set up at the IWK to record and collate the data and store it using a common time stamp.

POTENTIAL IN COMPOUNDING AND EXTRUSION

Overwiew of the most influencing parameter of the compounding process – simplified and divided into process steps





Source: OST; graphic: © Hanser

Possible use cases for the compounding process

Use Case	Description
Direct improvement of product quality / process stability	With real-time access to the data and information during the process, material characteristics can be kept constant. Based on the historical data, disturbance patterns can be detected by machine learning.
Indirect improvement of product quality	Different qualities / material properties are produced, to mix the different batches in a further step in such a way that, for example, the desired viscosity is achieved.
Remote access	The operator can access the most important process parameters of the complete plant online and in real time. In addition to that, the most important information and specifically desired data are provided, for example on monitors at the desired locations.
Predictive maintenance	Through the targeted installation of sensors and the recording in a central database, the wear of the plant can be monitored and optimized; access by external experts and thus early and more efficient maintenance measures
Logistics	The complete storage information of the materials used is recorded and entered into the data structure as an upstream process. This enables traceability in case of process variations and monitoring and optimization of storage.
Optimization of energy efficiency	Centrally recorded data for the entire plant, including all peripheral units, provide an overview of current and past energy consumption for various processes and configurations. This data is the basis for optimizing energy efficiency.

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- End-to-end digital product lifecycle management (PLM)
- Potential in compounding and extrusion
- Conclusions

Conclusions

- **Digitalization** offers **many opportunities**
- What are the interesting **uses cases** for my company? – Start with a workshop
- **Universities** work in different research areas - they can provide valuable support
- Digitalization requires collaboration between **different disciplines**

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