



Management Intelligence Services
Prof. Dr. Freimut Bodendorf

Winter term 23/24
Advanced Business Analytics Seminar
Project Kick-Off

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Analysis of continuous manufacturing sensor data with REHAU: polymer extrusion

The transformation to Industry 4.0 comes with a steady increase in complexity in the operation of systems as well as the control of production processes. Simultaneously new technologies open up potentials for service improvement and cost reduction. Due to the increasing digitization of machines, ever-greater quantities of data are recorded. Data-driven methods therefore offer themselves to mitigate the increasing complexity and realize potentials.

Data:

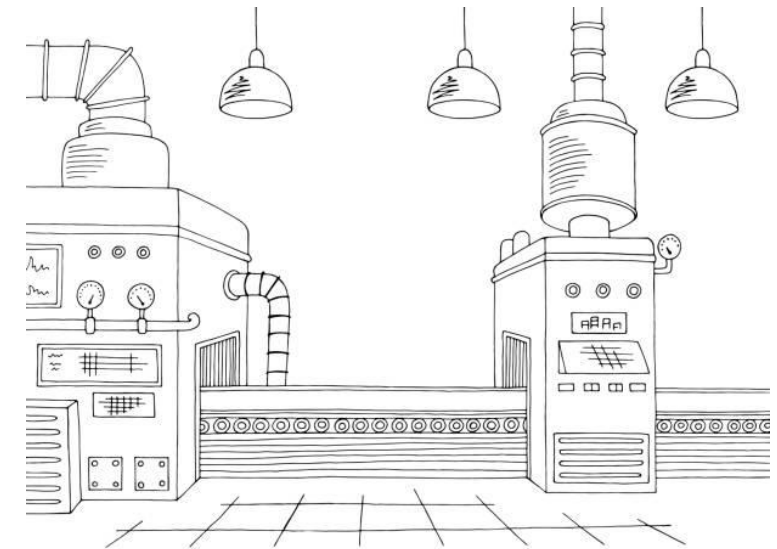
- Real-world manufacturing sensor data (messy)
- Continuous process (time-offsets)
- Fuzzy domain knowledge (research, initiative, iterations)
- Dataset: > 3M rows, > 30 columns

Tasks:

- Identify polymer extrusion process dependencies and causalities
- Build data-driven process-model from data

Vision:

- Model to simulate “what-if-scenarios”



In Cooperation with:



1 **Production Scenario**

2 **Production Data**

3 **Problem Statement**

4 **Data Access**

5 **Next Steps**

1 **Production Scenario**

2 **Production Data**

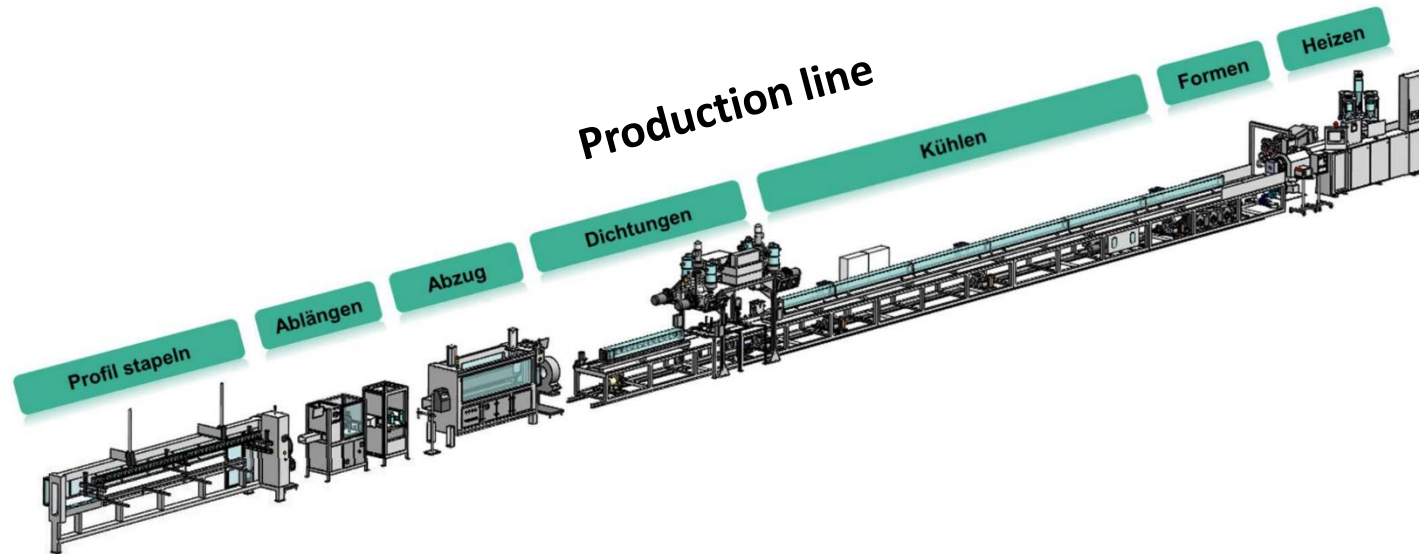
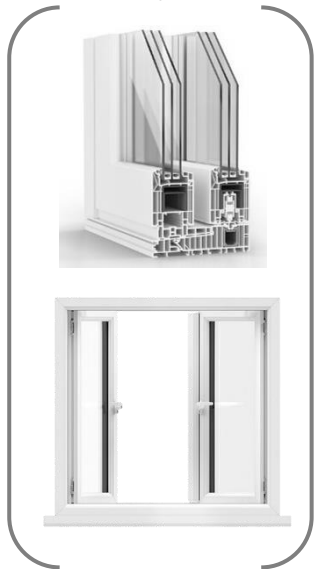
3 **Problem Statement**

4 **Data Access**

5 **Next Steps**

- Continuous production of window frames

Output

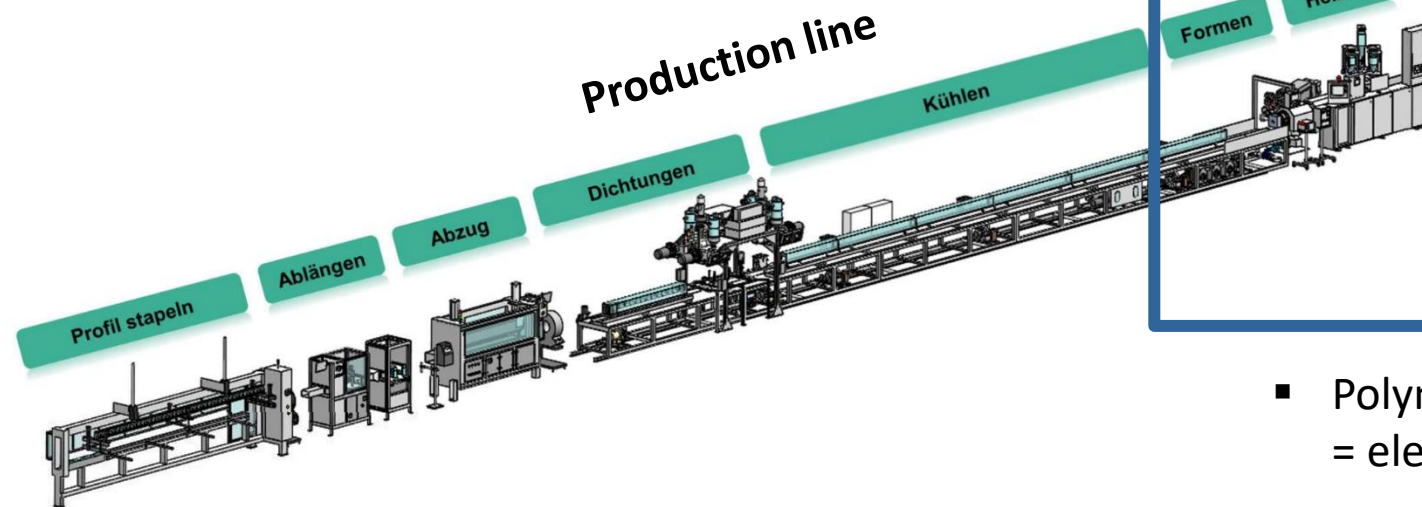
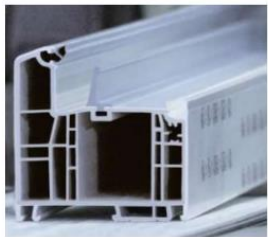


Input



- Continuous production of window frames

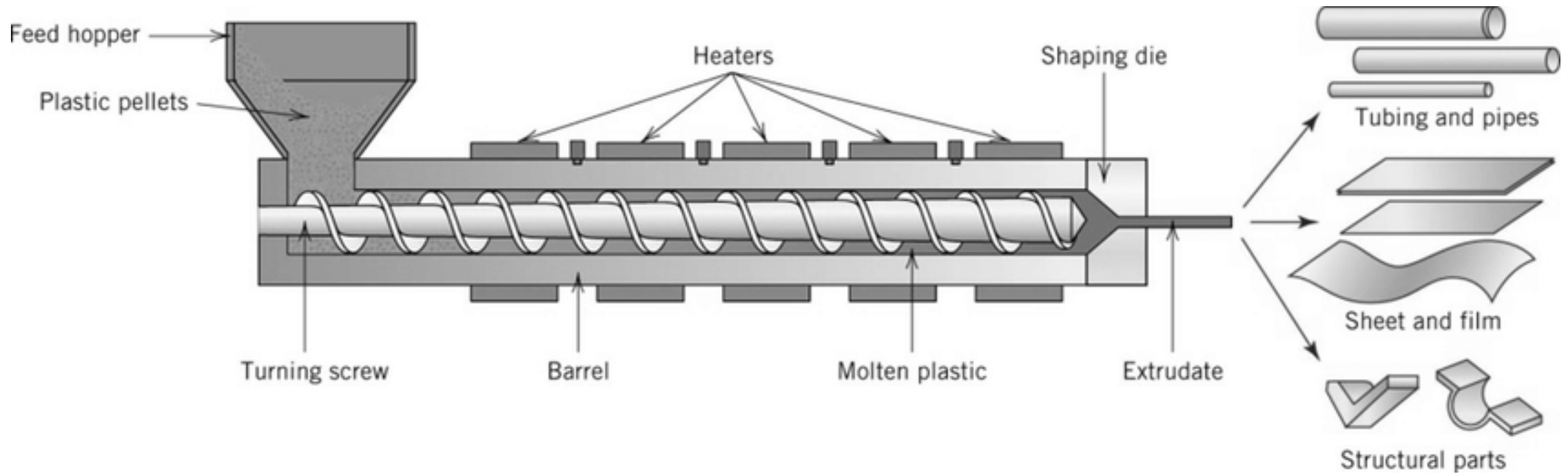
Output



Input



- Polymer extrusion process = element of analysis



1 **Production Scenario**

2 **Production Data**

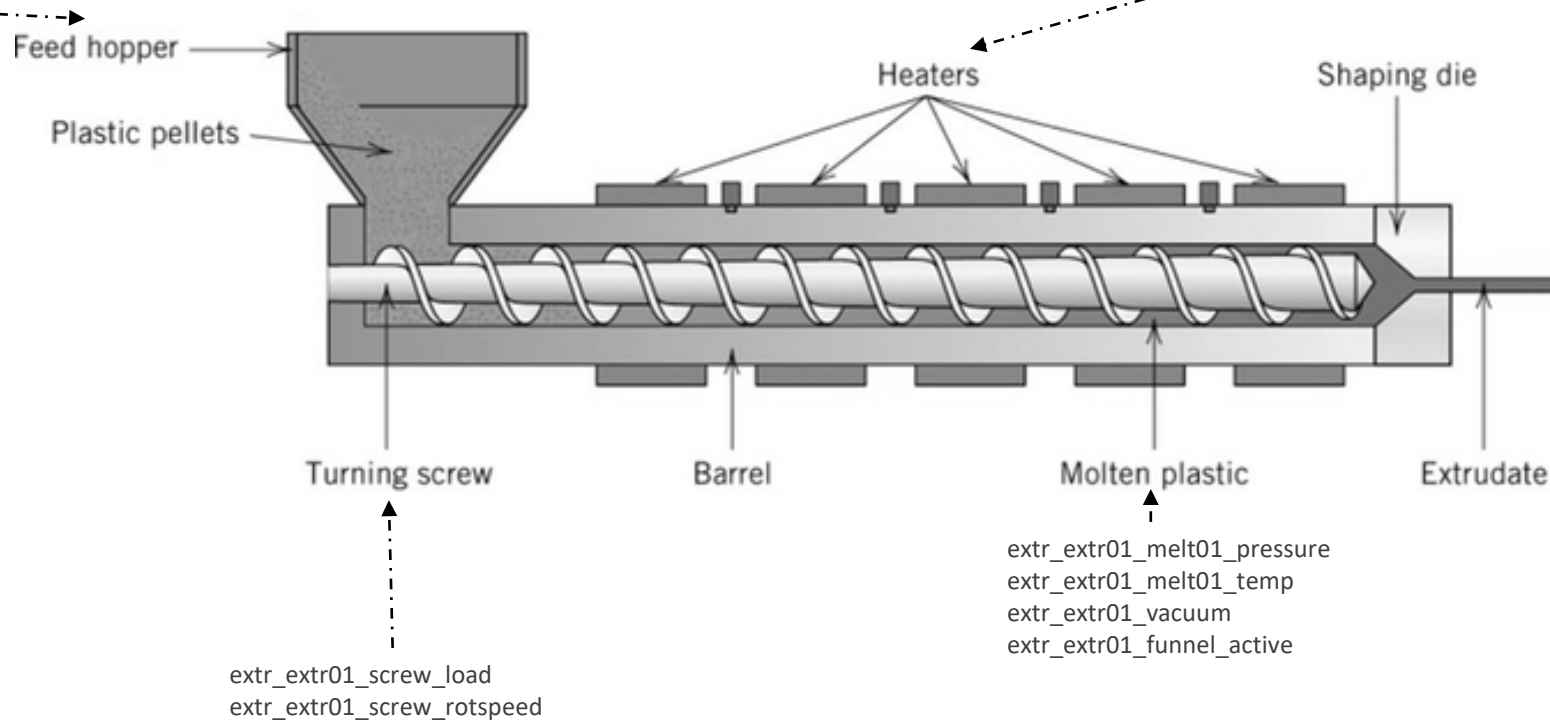
3 **Problem Statement**

4 **Data Access**

5 **Next Steps**

Sensor process data

dose_grav01_hopper01_mattemp
dose_grav01_hopper01_powerin
dose_grav01_hopper01_rotspeed
dose_grav01_hopper01_throughput
dose_grav01_hopper01_weight
dose_grav01_hopper02_mattemp
dose_grav01_hopper02_powerin
dose_grav01_hopper02_rotspeed
dose_grav01_hopper02_throughput
dose_grav01_hopper02_weight
dose_grav01_hopper03_mattemp
dose_grav01_hopper03_powerin
dose_grav01_hopper03_rotspeed
dose_grav01_hopper03_throughput
dose_grav01_hopper03_weight
dose_grav01_hopper04_mattemp
dose_grav01_hopper04_powerin
dose_grav01_hopper04_rotspeed
dose_grav01_hopper04_throughput
dose_grav01_hopper04_weight
dose_grav01_hopper05_mattemp
dose_grav01_hopper05_powerin
dose_grav01_hopper05_rotspeed
dose_grav01_hopper05_throughput
dose_grav01_hopper05_weight
dose_grav01_total_throughput

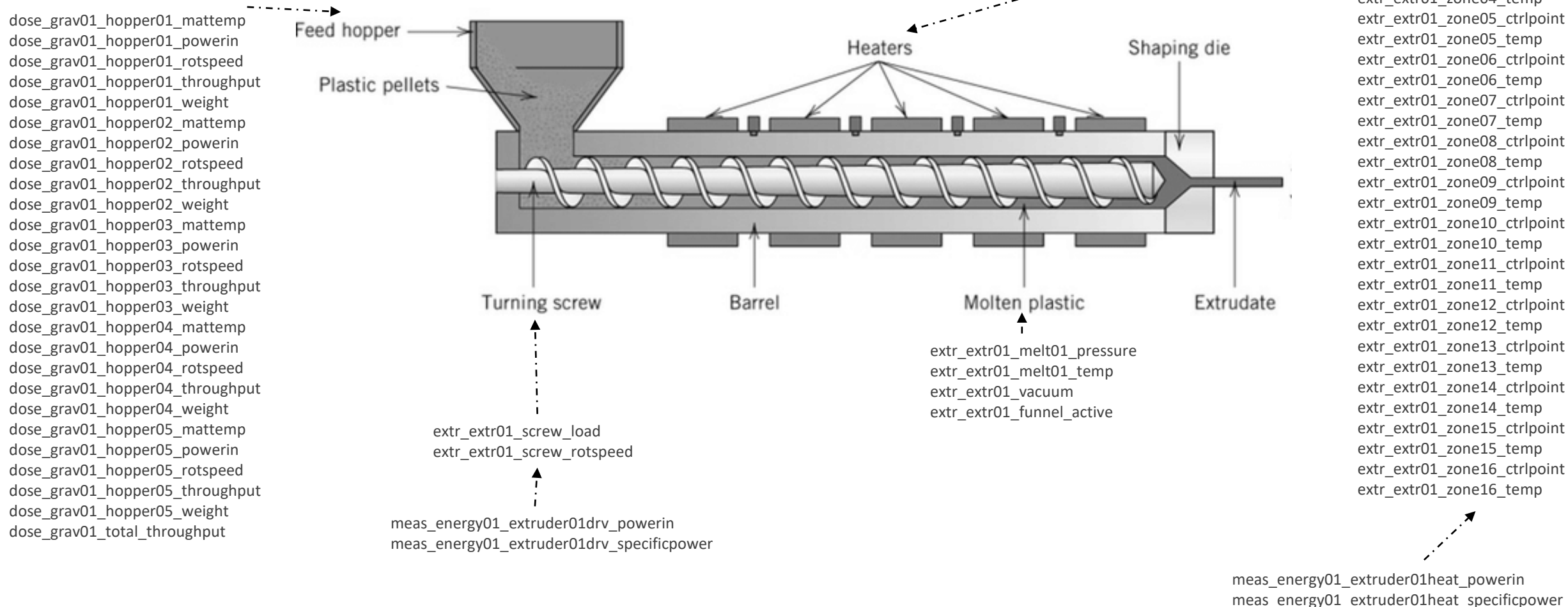


extr_extr01_screw_load
extr_extr01_screw_rotspeed

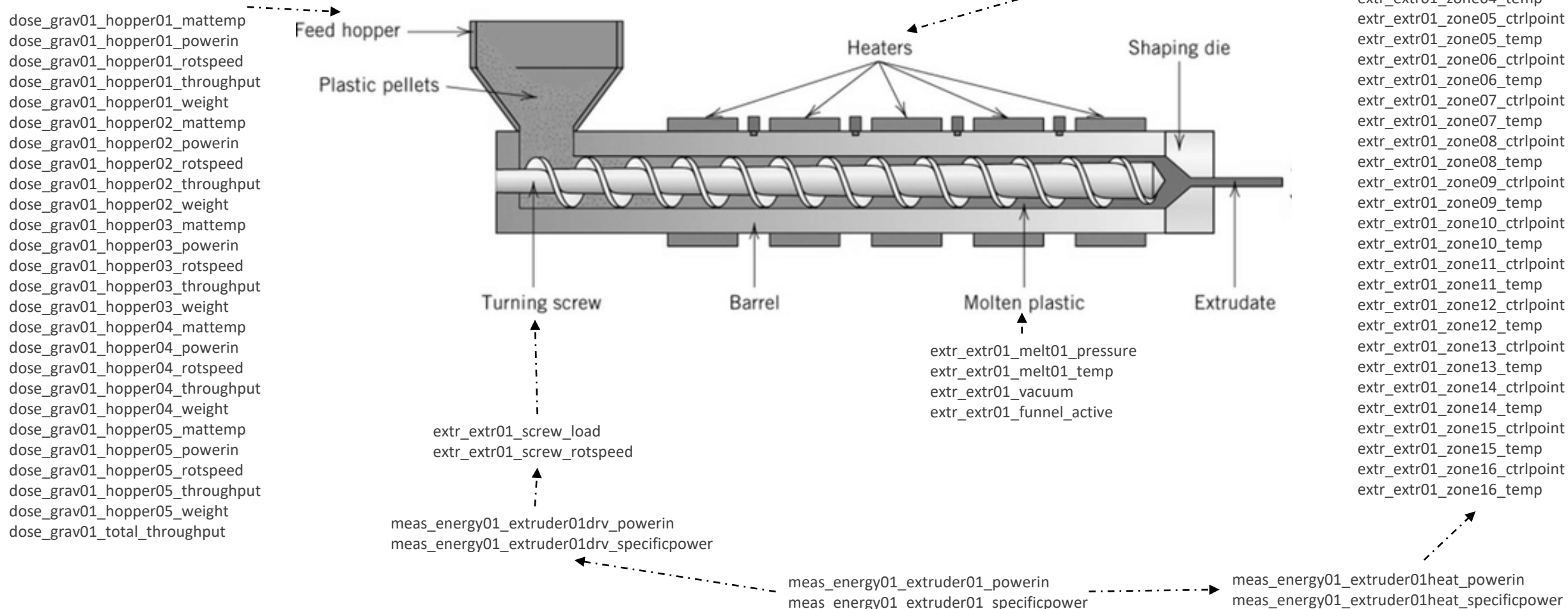
extr_extr01_melt01_pressure
extr_extr01_melt01_temp
extr_extr01_vacuum
extr_extr01_funnel_active

extr_extr01_zone01_ctrlpoint
extr_extr01_zone01_temp
extr_extr01_zone02_ctrlpoint
extr_extr01_zone02_temp
extr_extr01_zone03_ctrlpoint
extr_extr01_zone03_temp
extr_extr01_zone04_ctrlpoint
extr_extr01_zone04_temp
extr_extr01_zone05_ctrlpoint
extr_extr01_zone05_temp
extr_extr01_zone06_ctrlpoint
extr_extr01_zone06_temp
extr_extr01_zone07_ctrlpoint
extr_extr01_zone07_temp
extr_extr01_zone08_ctrlpoint
extr_extr01_zone08_temp
extr_extr01_zone09_ctrlpoint
extr_extr01_zone09_temp
extr_extr01_zone10_ctrlpoint
extr_extr01_zone10_temp
extr_extr01_zone11_ctrlpoint
extr_extr01_zone11_temp
extr_extr01_zone12_ctrlpoint
extr_extr01_zone12_temp
extr_extr01_zone13_ctrlpoint
extr_extr01_zone13_temp
extr_extr01_zone14_ctrlpoint
extr_extr01_zone14_temp
extr_extr01_zone15_ctrlpoint
extr_extr01_zone15_temp
extr_extr01_zone16_ctrlpoint
extr_extr01_zone16_temp

Sensor process data



Sensor process data



DatetimeIndex: 6805340 entries, 2020-08-31 21:19:58.390000 to 2020-10-31 02:15:14.750000

Data columns (total 93 columns):

| # | Column | Non-Null Count | Dtype |
|-----|---|------------------|---------|
| 0 | dose_grav01_hopper01_mattemp_r_value_act | 93575 non-null | float64 |
| 1 | dose_grav01_hopper01_powerin_r_value_act | 1403371 non-null | float64 |
| 2 | dose_grav01_hopper01_rotspeed_r_value_act | 1403371 non-null | float64 |
| 3 | dose_grav01_hopper01_throughput_r_value_act | 1403371 non-null | float64 |
| 4 | dose_grav01_hopper01_throughput_r_value_set | 1403371 non-null | float64 |
| 5 | dose_grav01_hopper01_weight_r_value_act | 1403371 non-null | float64 |
| 6 | dose_grav01_hopper02_mattemp_r_value_act | 93575 non-null | float64 |
| 7 | dose_grav01_hopper02_powerin_r_value_act | 1403371 non-null | float64 |
| 8 | dose_grav01_hopper02_rotspeed_r_value_act | 1403371 non-null | float64 |
| 9 | dose_grav01_hopper02_throughput_r_value_act | 1403371 non-null | float64 |
| 10 | dose_grav01_hopper02_throughput_r_value_set | 1403371 non-null | float64 |
| 11 | dose_grav01_hopper02_weight_r_value_act | 1403371 non-null | float64 |
| 12 | dose_grav01_hopper03_mattemp_r_value_act | 93575 non-null | float64 |
| 13 | dose_grav01_hopper03_powerin_r_value_act | 1403371 non-null | float64 |
| 14 | dose_grav01_hopper03_rotspeed_r_value_act | 1403371 non-null | float64 |
| 15 | dose_grav01_hopper03_throughput_r_value_act | 1403371 non-null | float64 |
| 16 | dose_grav01_hopper03_throughput_r_value_set | 1403371 non-null | float64 |
| 17 | dose_grav01_hopper03_weight_r_value_act | 1403371 non-null | float64 |
| 18 | dose_grav01_hopper04_mattemp_r_value_act | 93575 non-null | float64 |
| 19 | dose_grav01_hopper04_powerin_r_value_act | 1403371 non-null | float64 |
| ... | | | |
| 92 | timecode | 6805340 non-null | object |

dtypes: float64(87), int64(1), object(5)
memory usage: 4.8+ GB

Sensor process data

dose_grav01_hopper01_mattemp
dose_grav01_hopper01_powerin
dose_grav01_hopper01_rotspeed
dose_grav01_hopper01_throughput
dose_grav01_hopper01_weight
dose_grav01_hopper02_mattemp
dose_grav01_hopper02_powerin
dose_grav01_hopper02_rotspeed
dose_grav01_hopper02_throughput
dose_grav01_hopper02_weight
dose_grav01_hopper03_mattemp
dose_grav01_hopper03_powerin
dose_grav01_hopper03_rotspeed
dose_grav01_hopper03_throughput
dose_grav01_hopper03_weight
dose_grav01_hopper04_mattemp
dose_grav01_hopper04_powerin
dose_grav01_hopper04_rotspeed
dose_grav01_hopper04_throughput
dose_grav01_hopper04_weight
dose_grav01_hopper05_mattemp
dose_grav01_hopper05_powerin
dose_grav01_hopper05_rotspeed
dose_grav01_hopper05_throughput
dose_grav01_hopper05_weight
dose_grav01_total_throughput

meas_energy01_extruder01drv_powerin
meas_energy01_extruder01drv_specificpower
meas_energy01_extruder01_powerin
meas_energy01_extruder01_specificpower
meas_energy01_extruder01heat_powerin
meas_energy01_extruder01heat_specificpower

extr_extr01_zone01_ctrlpoint
extr_extr01_zone01_temp
extr_extr01_zone02_ctrlpoint
extr_extr01_zone02_temp
extr_extr01_zone03_ctrlpoint
extr_extr01_zone03_temp
extr_extr01_zone04_ctrlpoint
extr_extr01_zone04_temp
extr_extr01_zone05_ctrlpoint
extr_extr01_zone05_temp
extr_extr01_zone06_ctrlpoint
extr_extr01_zone06_temp
extr_extr01_zone07_ctrlpoint
extr_extr01_zone07_temp
extr_extr01_zone08_ctrlpoint
extr_extr01_zone08_temp
extr_extr01_zone09_ctrlpoint
extr_extr01_zone09_temp
extr_extr01_zone10_ctrlpoint
extr_extr01_zone10_temp
extr_extr01_zone11_ctrlpoint
extr_extr01_zone11_temp
extr_extr01_zone12_ctrlpoint
extr_extr01_zone12_temp
extr_extr01_zone13_ctrlpoint
extr_extr01_zone13_temp
extr_extr01_zone14_ctrlpoint
extr_extr01_zone14_temp
extr_extr01_zone15_ctrlpoint
extr_extr01_zone15_temp
extr_extr01_zone16_ctrlpoint
extr_extr01_zone16_temp

extr_extr01_melt01_pressure
extr_extr01_melt01_temp
extr_extr01_screw_load
extr_extr01_screw_rotspeed
extr_extr01_vacuum
extr_extr01_funnel_active

Meta-Data (MES¹/ERP²/etc.)

| | |
|--------------|--|
| _time | Sensor measurement time |
| segment_nr | Counter of production interval; based on identical timecode & order |
| article_type | Type of produced article (categorical) |
| basematerial | Type of main material (categorical) |
| order | Order number (ID) |
| recipe | Used recipe (categorical) |
| timecode | 000 == production time (in line with specifications) 3XX == machine failure time 4XX == article failure time |

¹ Manufacturing execution system
² Enterprise resource planing

Sensor process data

| | dose_grav01_hopper01_rotspeed_r_value_act | dose_grav01_hopper01_throughput_r_value_act | dose_grav01_hopper01_throughput_r_value_set |
|-------------------------|---|---|---|
| _time | | | |
| 2020-08-31 21:19:58.390 | NaN | NaN | NaN |
| 2020-08-31 21:19:58.900 | NaN | NaN | NaN |
| 2020-08-31 21:19:59.300 | 0.0 | 0.0 | 0.0 |
| 2020-08-31 21:19:59.420 | NaN | NaN | NaN |
| 2020-08-31 21:19:59.930 | NaN | NaN | NaN |
| 2020-08-31 21:20:00.450 | NaN | NaN | NaN |
| 2020-08-31 21:20:00.960 | NaN | NaN | NaN |
| 2020-08-31 21:20:01.300 | 0.0 | 0.0 | 0.0 |
| 2020-08-31 21:20:01.480 | NaN | NaN | NaN |
| 2020-08-31 21:20:01.990 | NaN | NaN | NaN |

r_value_act =
actual measure value

Meta data

| article_type | order | recipe | basematerial | timecode |
|--------------|-------|--------|--------------|----------|
| 2 | 0 | 2 | 1 | 0 |
| 2 | 0 | 2 | 1 | 0 |
| 2 | 0 | 2 | 1 | 0 |
| 2 | 0 | 2 | 1 | 0 |
| 2 | 0 | 2 | 1 | 0 |
| 2 | 0 | 2 | 1 | 0 |
| 2 | 0 | 2 | 1 | 0 |
| 2 | 0 | 2 | 1 | 0 |
| 2 | 0 | 2 | 1 | 0 |
| 2 | 0 | 2 | 1 | 0 |

...

1 Production Scenario

2 Production Data

3 Problem Statement

4 Data Access

5 Next Steps

Consulting Project:

- Identify polymer extrusion process dependencies and causalities
 - How do sensor parameters influence each other? (time-delays, magnitude)
 - Build data-driven process-model from data (“Extruder-Model”)
 - Model to simulate „what-if“-scenarios
-
- Your initiative is required to further specify the requirements.
 - Some form of project management is highly recommended.

Causal discovery/inference:

- Vuković, M.; Thalmann, S. Causal Discovery in Manufacturing: A Structured Literature Review. J. Manuf. Mater. Process. 2022. <https://doi.org/10.3390/jmmp6010010>
- Runge, J.; Gerhardus, A.; Varando, G. et al.; Causal inference for time series. Nat Rev Earth Environ. 2023 <https://doi.org/10.1038/s43017-023-00431-y>
- [GitHub - jakobrunge/tigramite: Tigramite is a python package for causal inference with a focus on time series data](#)

1 Production Scenario

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- ABAWS2324.parquet

Do not share the data or other information outside of this seminar!

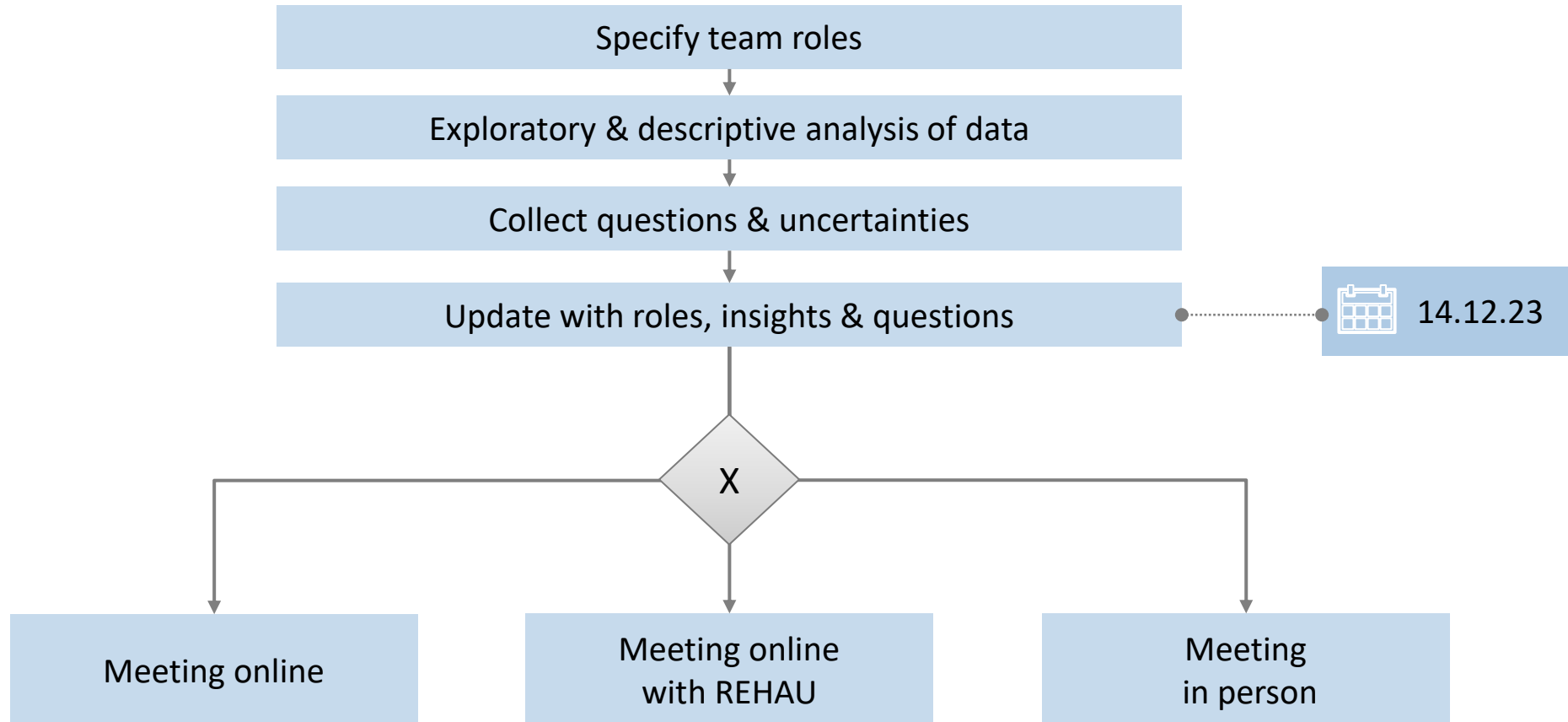
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Timeline & framework

