

# Predictive Maintenance using MATLAB: Pattern Matching for Time Series Data

Dr. Irina Ostapenko (Dr. Türck Ingenieurbüro GmbH),  
Jessica Fisch (Daimler AG)

26.06.2018



**Dr. Türck Ingenieurbüro**

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# Collaboration partners



Mercedes-Benz

Jessica Fisch

Mercedes-Benz Werk Mettingen

Digitale Fabrik Powertrain und Projekt Industrie 4.0

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**DR. TÜRCK**  **DATA SCIENCE**  
INGENIEURBÜRO

The logo for Dr. Türck Data Science features a stylized 'D' shape composed of a blue semi-circle on the left and a yellow semi-circle on the right.

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# Collaboration partners



Mercedes-Benz

Jessica Fisch

Focus:

- Digital Transformation
- Big Data
- IIoT

**DR. TÜRCK**  DATA SCIENCE  
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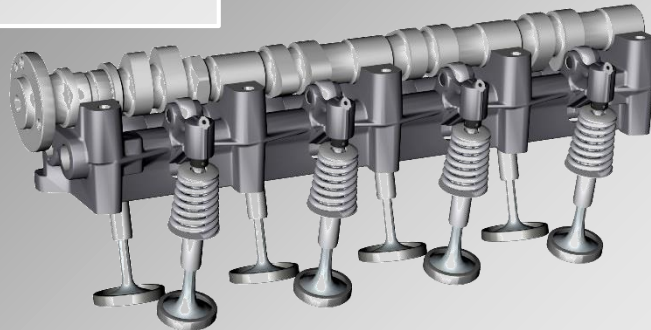
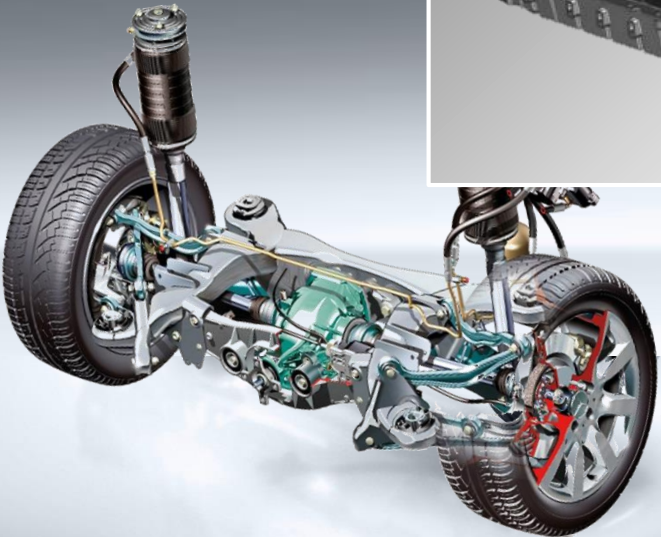
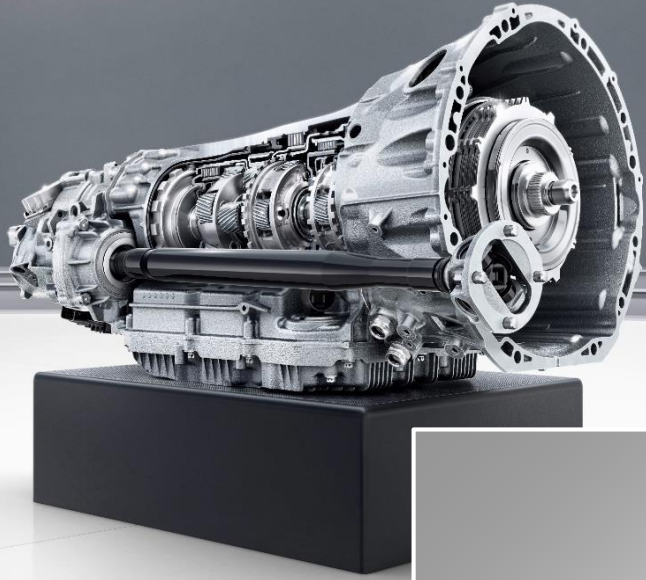
We provide

- Algorithms
- Signal Processing
- Measurement Systems Developing

Optical System Design

# Outline

1. Project introduction
2. Task description
3. Solution/Algorithm
4. Summary



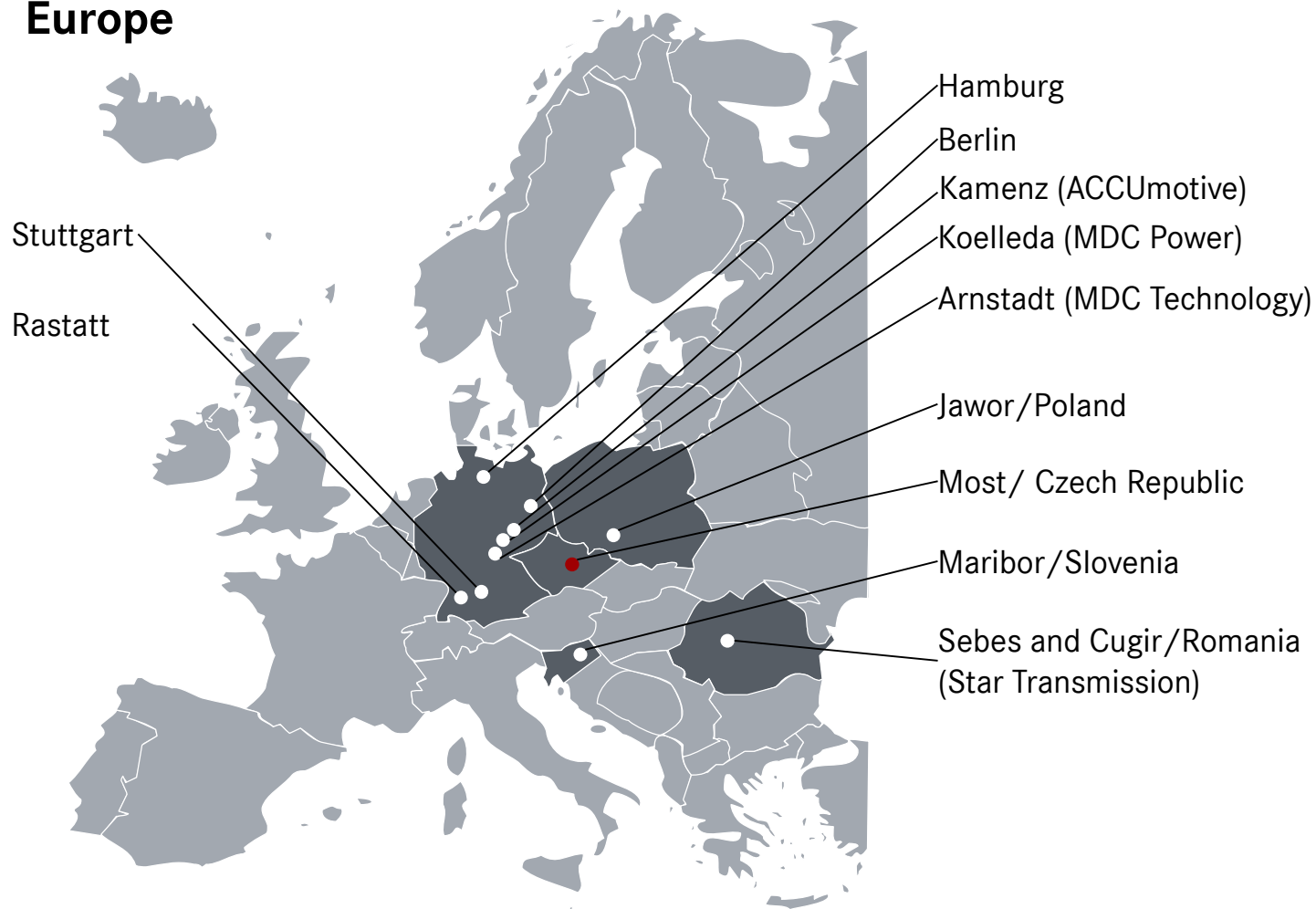
# P POWERTRAIN

Five modules form  
the core of our cars

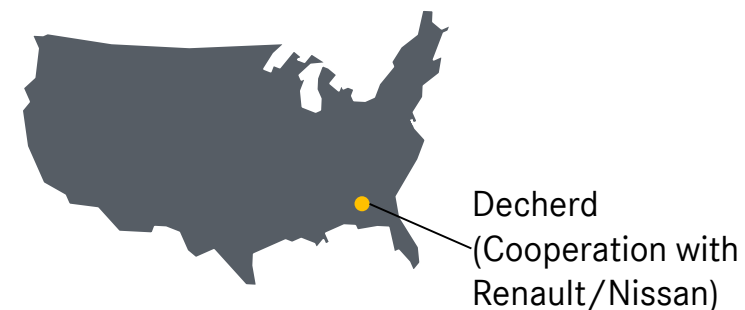


# The Powertrain production network is set up globally with lead plant in Germany

## Europe



## USA



## China



### Legend

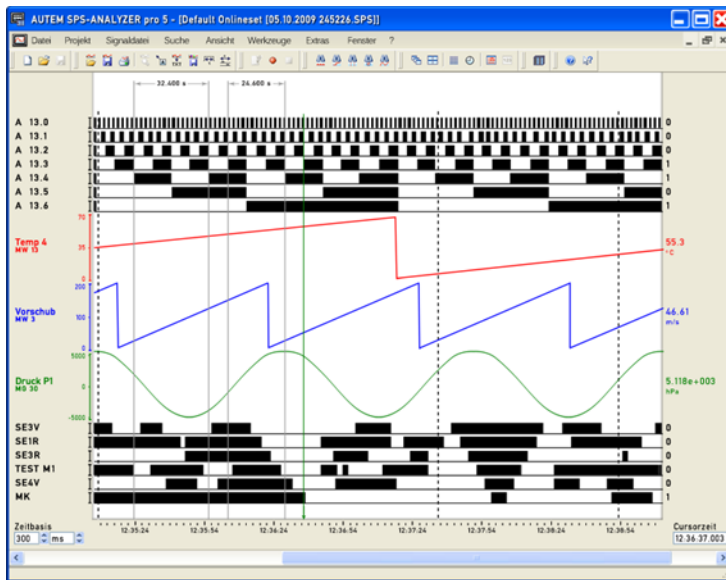
- 100% Daimler
- Majority Holding
- Joint Venture
- Cooperation

# Motivation for Anomaly Detection in the Projekt „iLL“



## The goal is to detect anomalies in data

PLC-Data today:

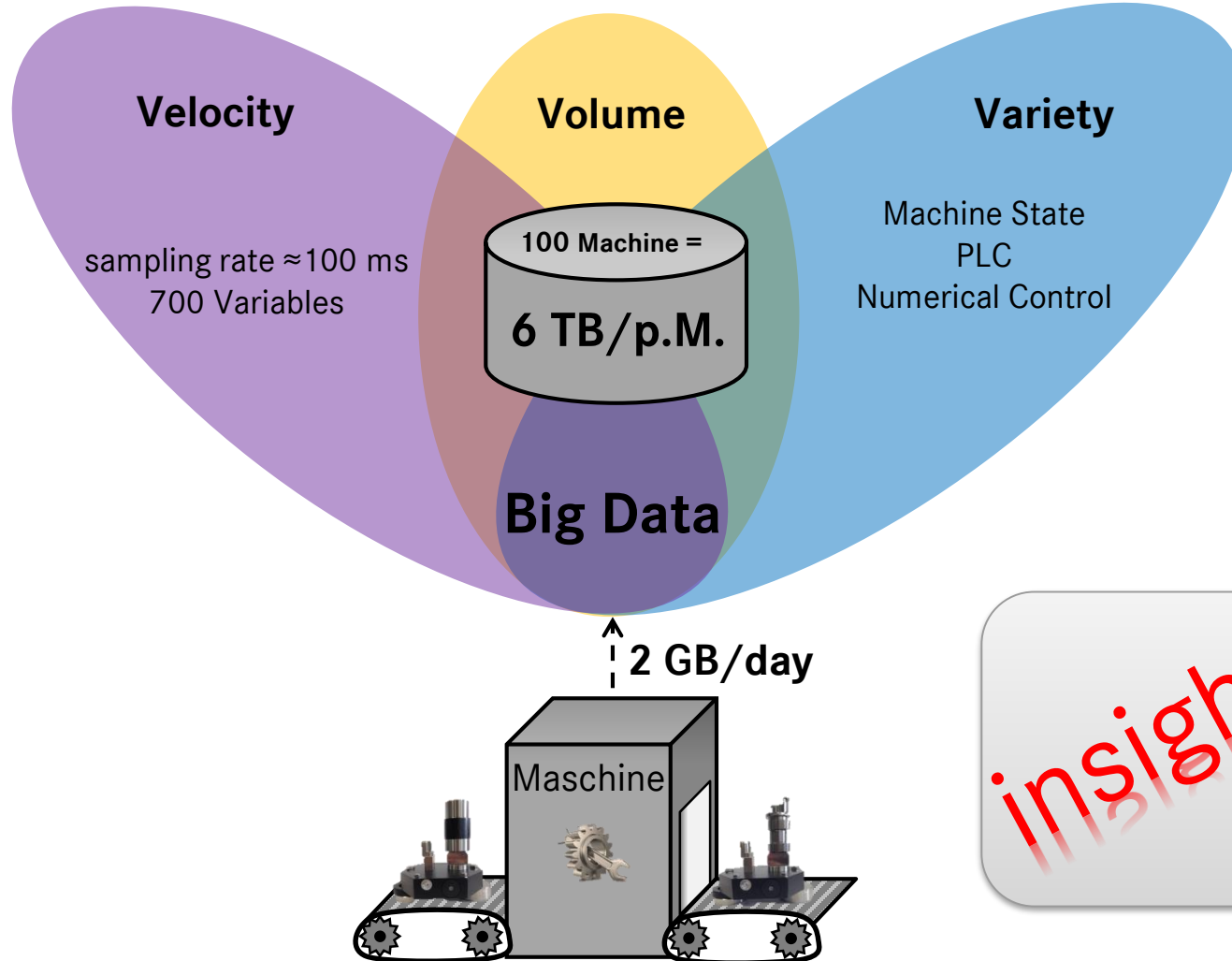


Source: [www.autem.de](http://www.autem.de)

Automatic Notification of the Deviation:



# Data properties in the context of Big Data



The 3 basic V's of Big Data:

- **Velocity:** Speed with which data is generated and analyzed
- **Volume:** Amount of data that traditionally can not be analyzed
- **Variety:** Data diversity refers to unstructured data without a recognizable context

The 2 additional V's:

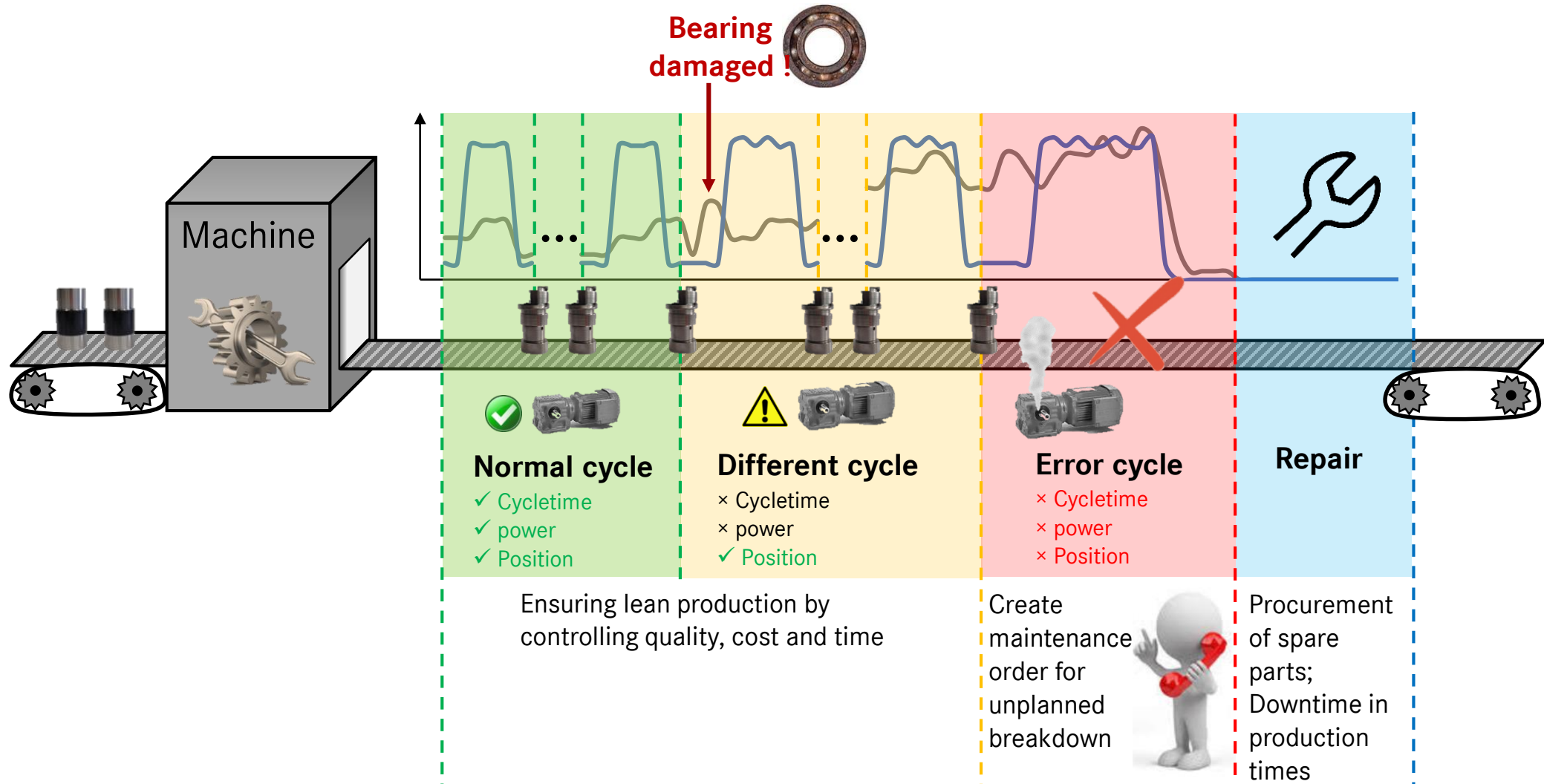
- **Validity:** Ensuring data quality
- **Value:** measurable benefits from the data

*insight*



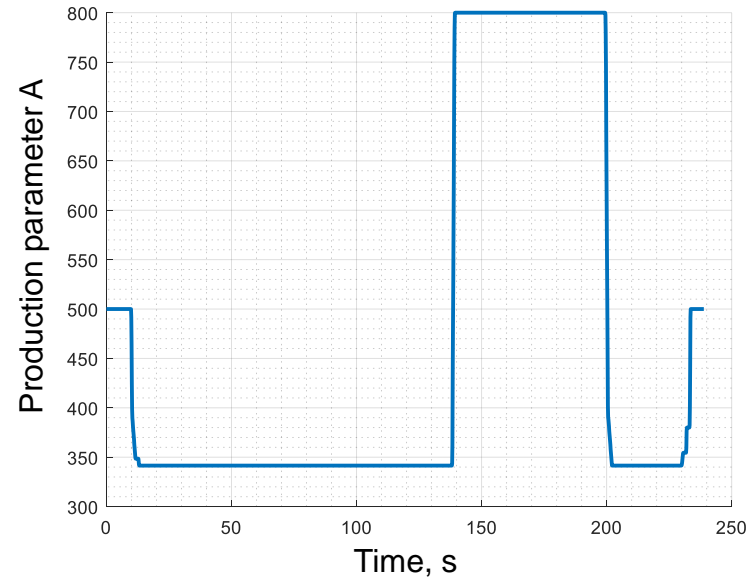
# Benefits of „Intelligent Level-Learning“

— Active power engine axis 1  
 — Position axis 1



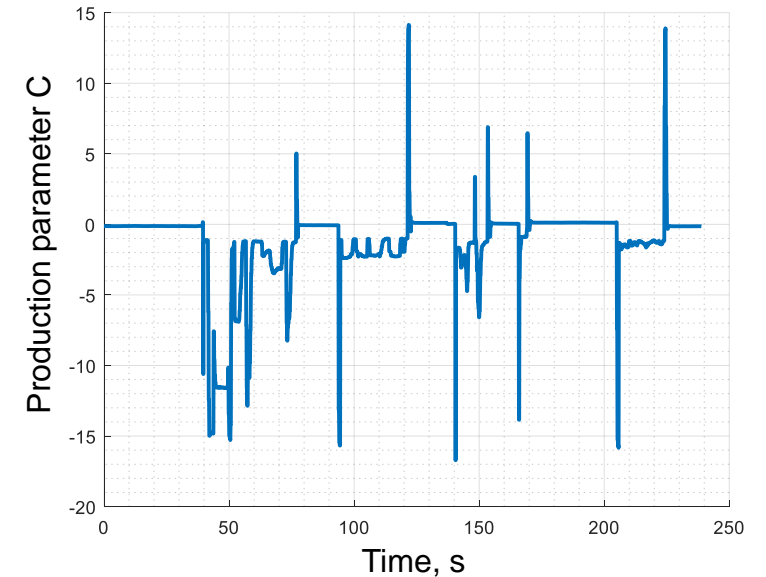
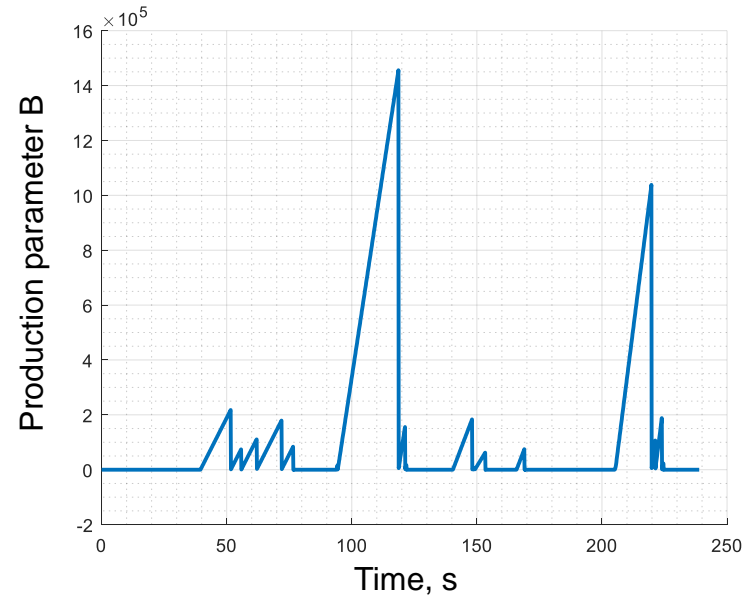
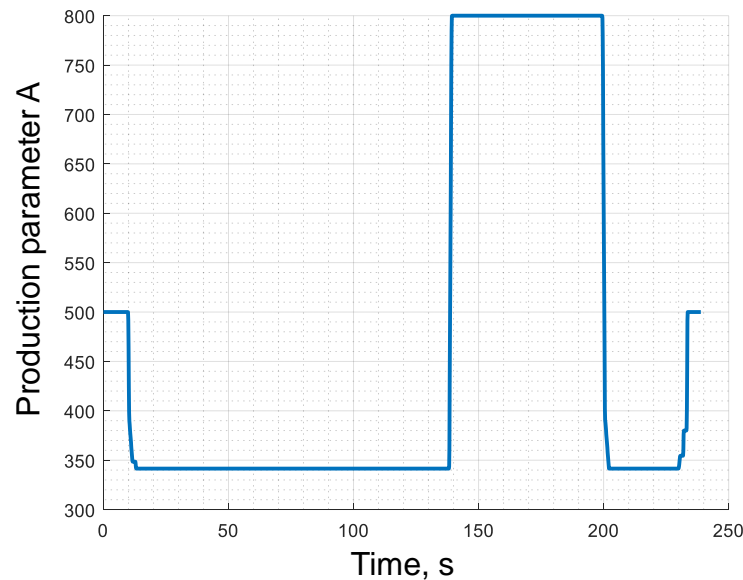
# Challenges

- About 700 parameters are continuously monitored in every production cycle yielding 700 individual time-series of about 2500 samples each



# Challenges

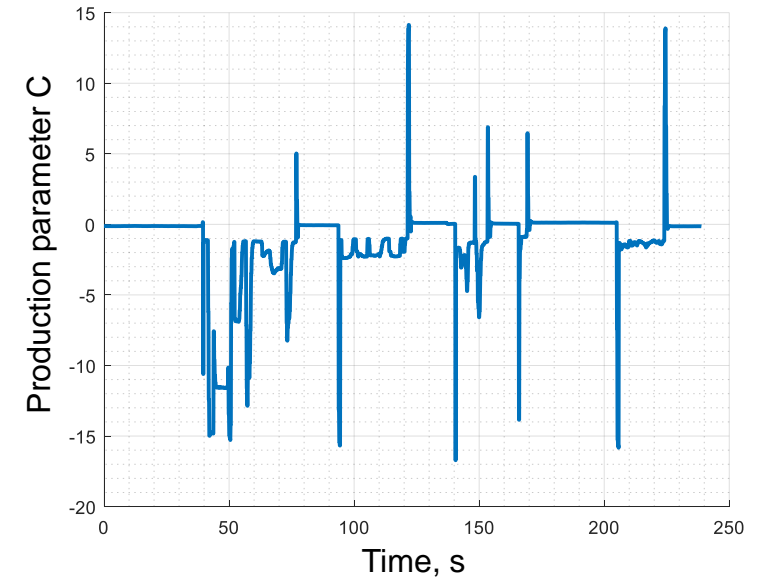
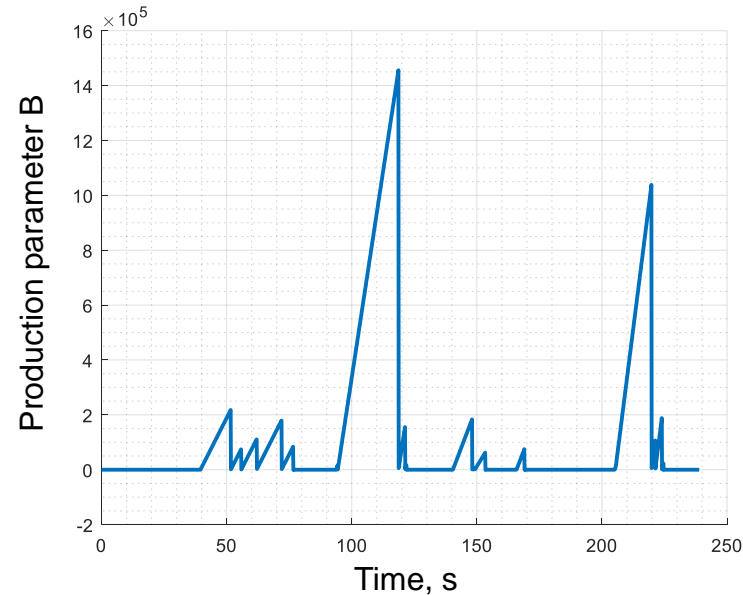
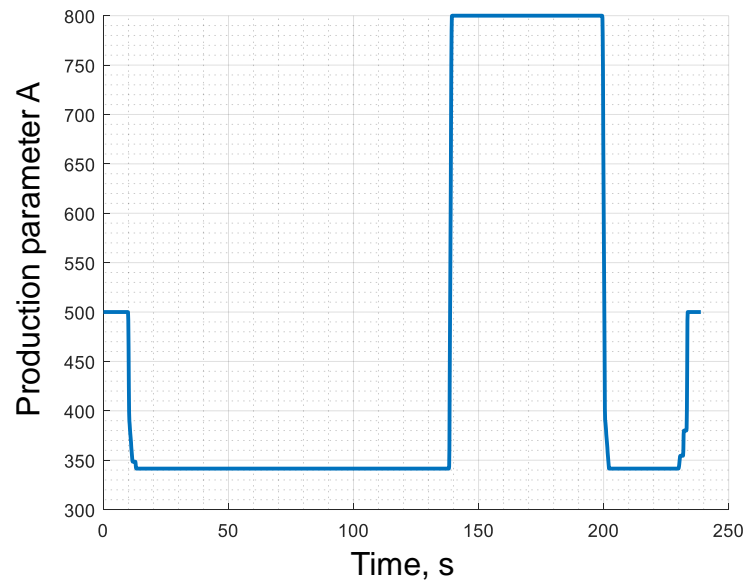
- About 700 parameters are continuously monitored in every production cycle yielding 700 individual time-series of about 2500 samples each



- Different parameters show very different and elaborate features

# Challenges

- About 700 parameters are continuously monitored in every production cycle yielding 700 individual time-series of about 2500 samples each

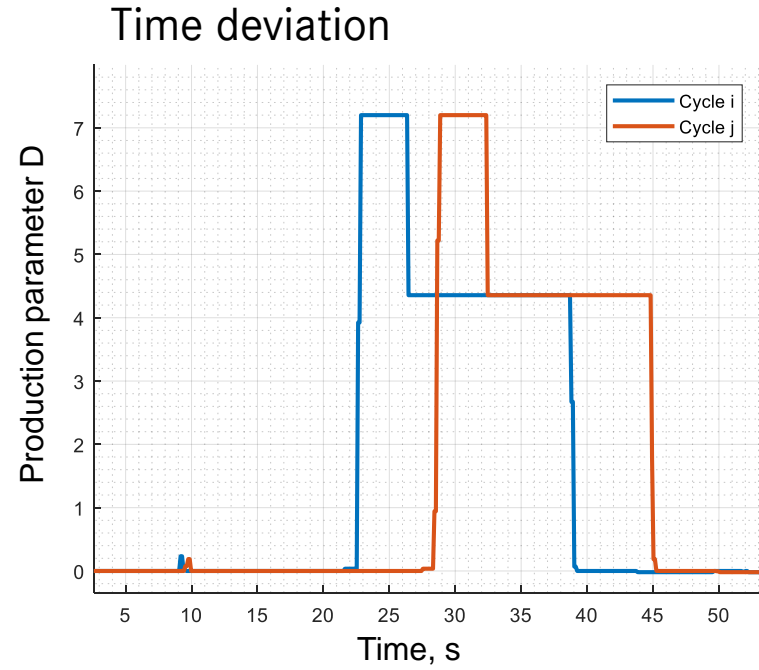


- Different parameters show very different and elaborate features



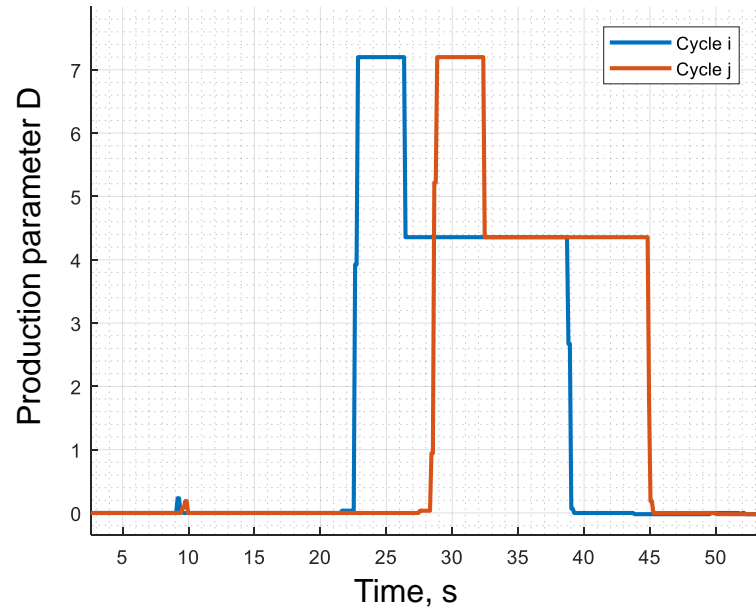
Task: Analyse these 700 time-series and find specific kinds of deviations

# Requirements for algorithm

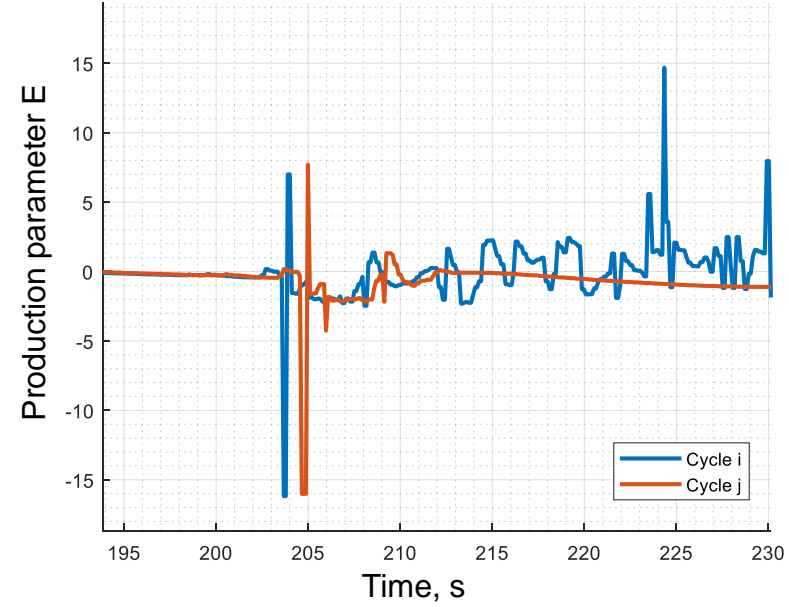


# Requirements for algorithm

## Time deviation

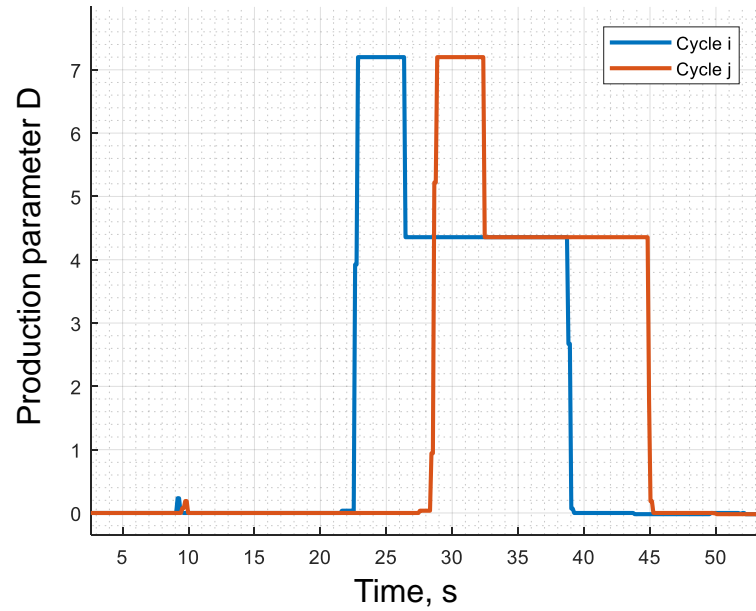


## Pattern deviation

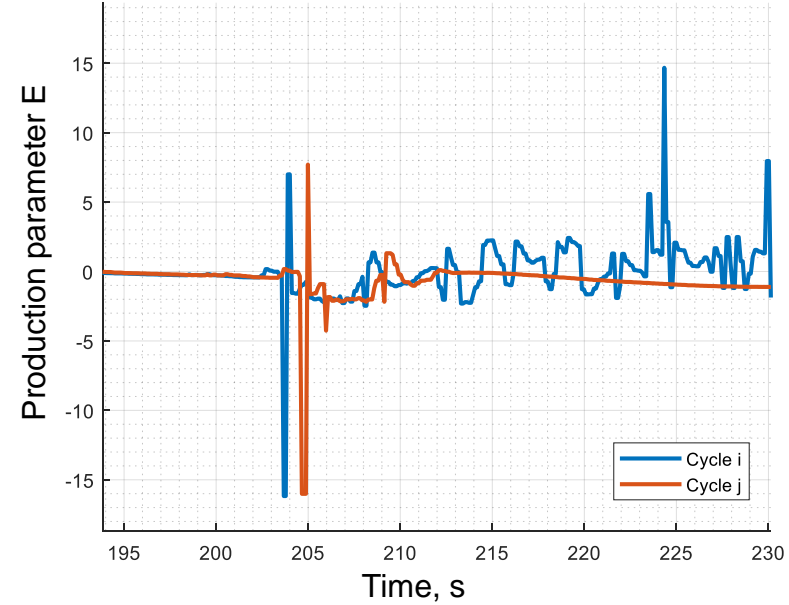


# Requirements for algorithm

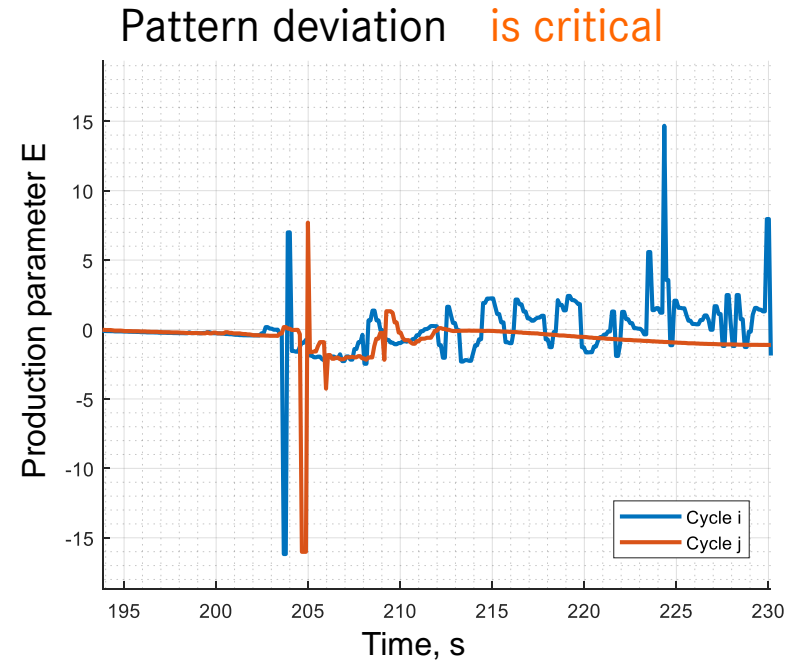
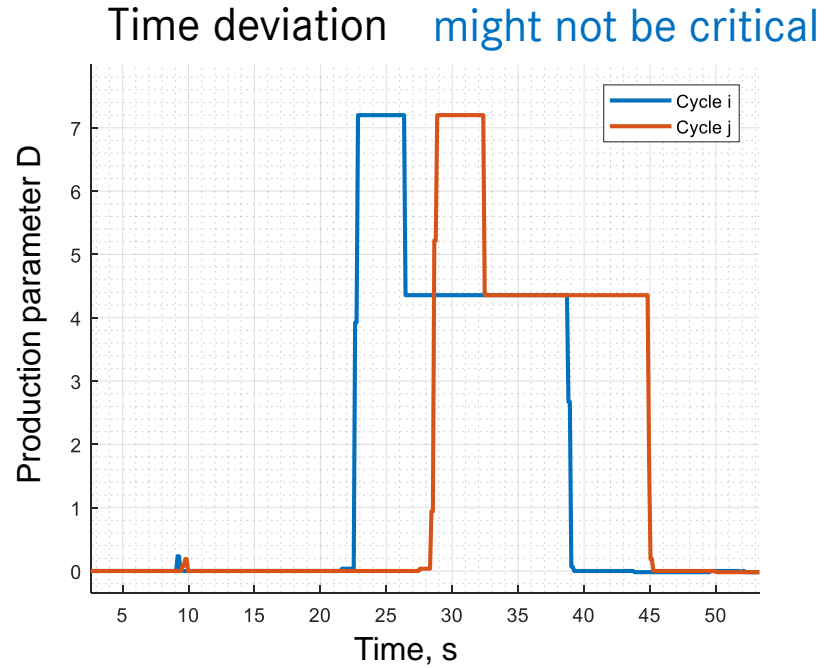
Time deviation **might not be critical**



Pattern deviation **is critical**



# Requirements for algorithm



What the algorithm should do

- Time series analysis
- Find deviations from normal cycle and
- Distinguishing between time and pattern deviation

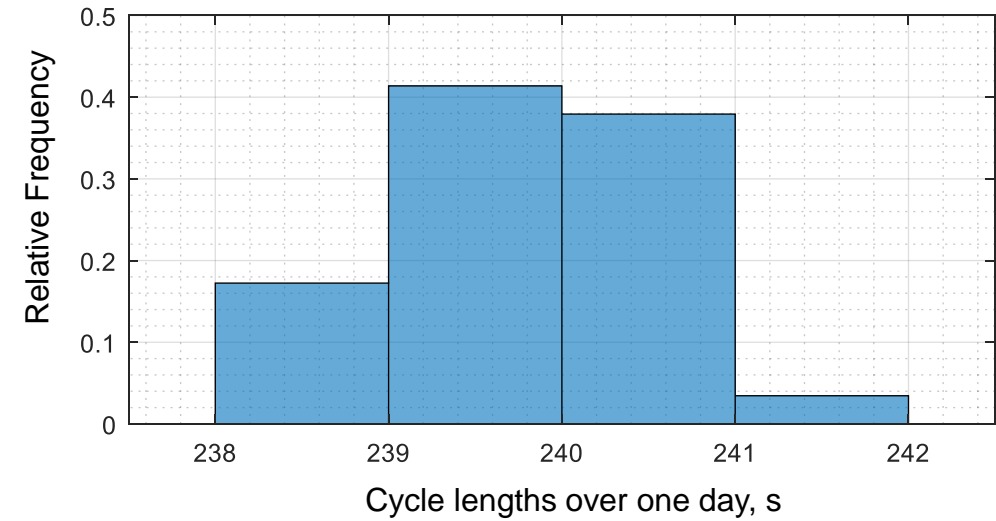
What is *normal*?





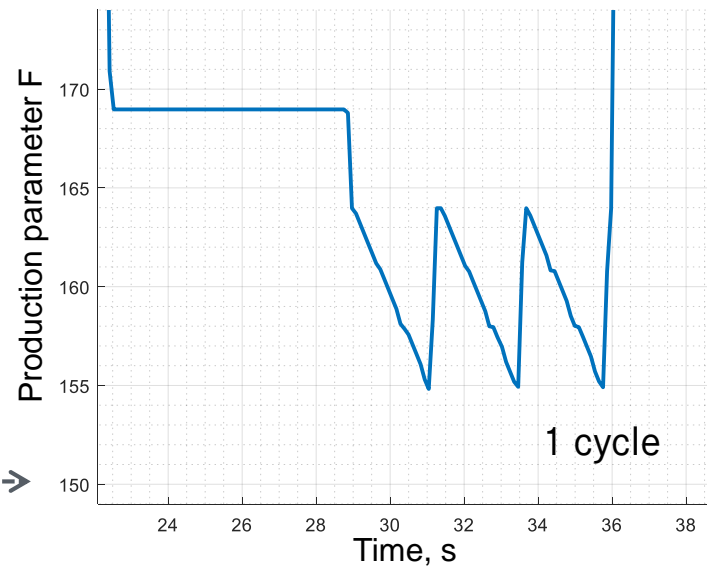
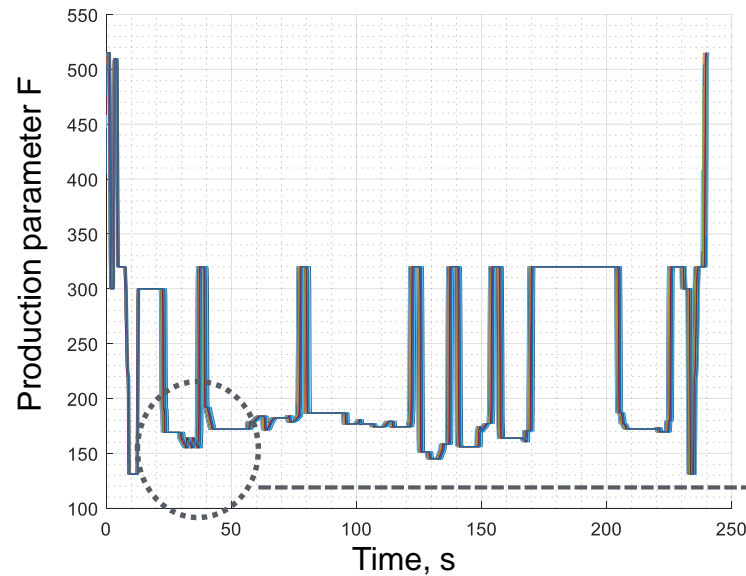
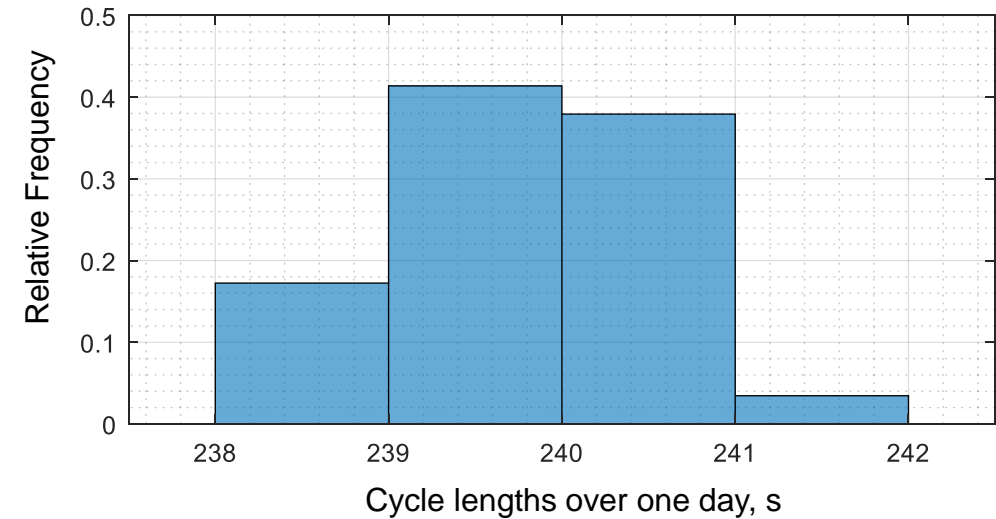
# Delays in production cycles

- Length of time-series varies from cycle to cycle even for normal production



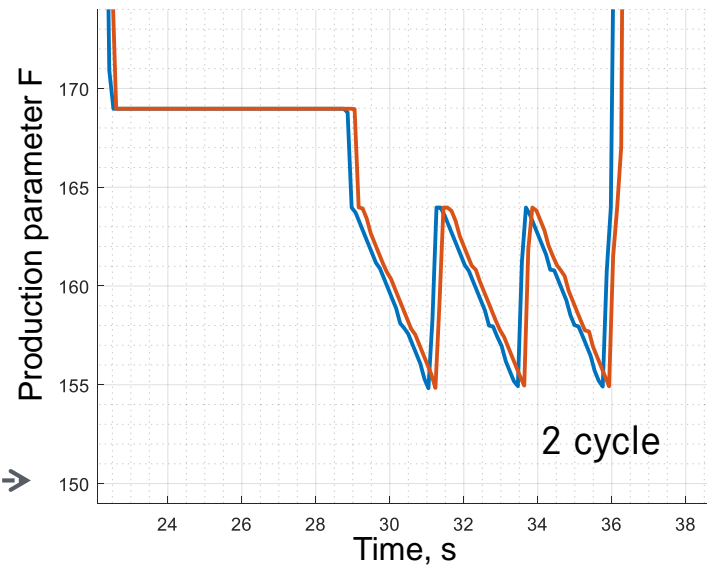
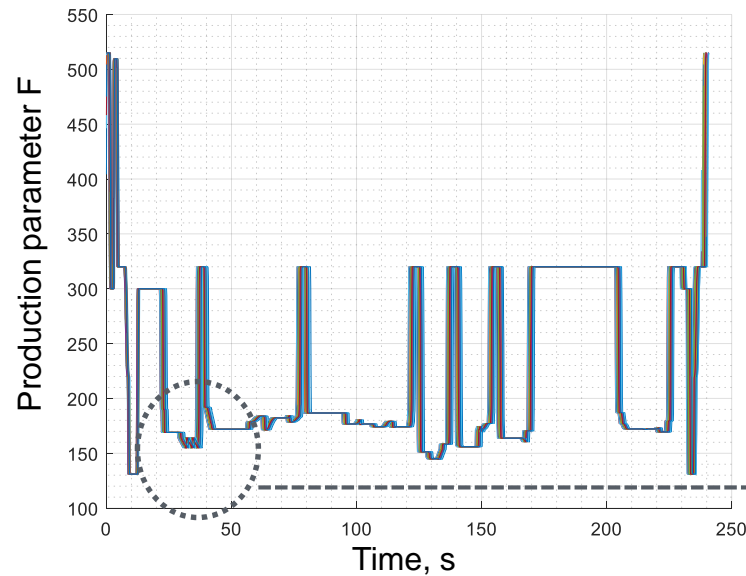
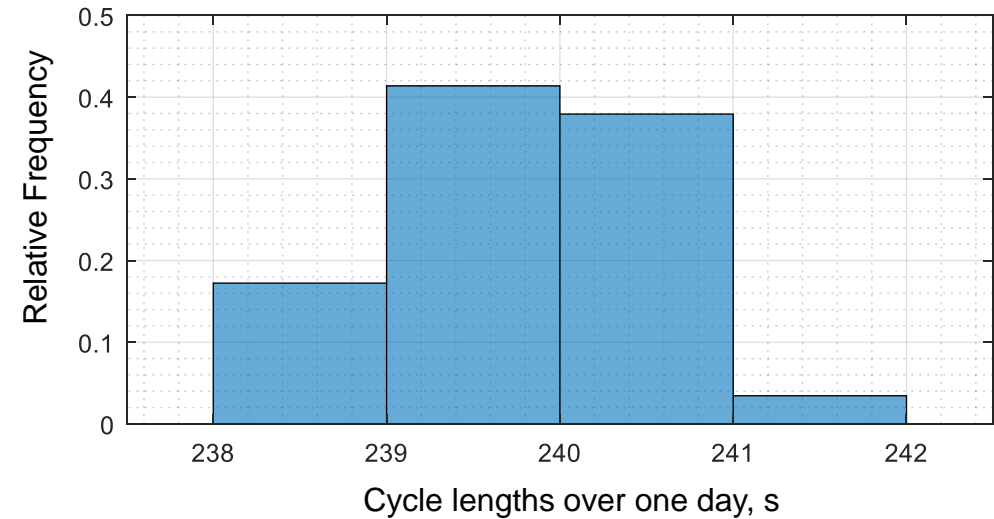
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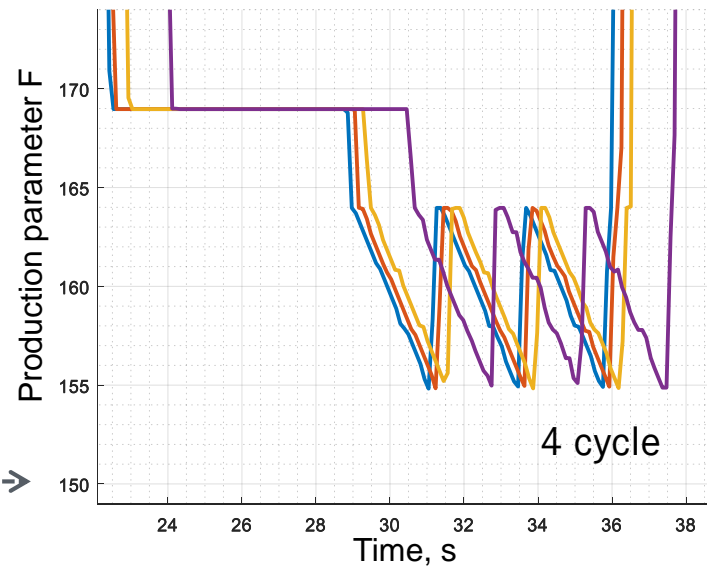
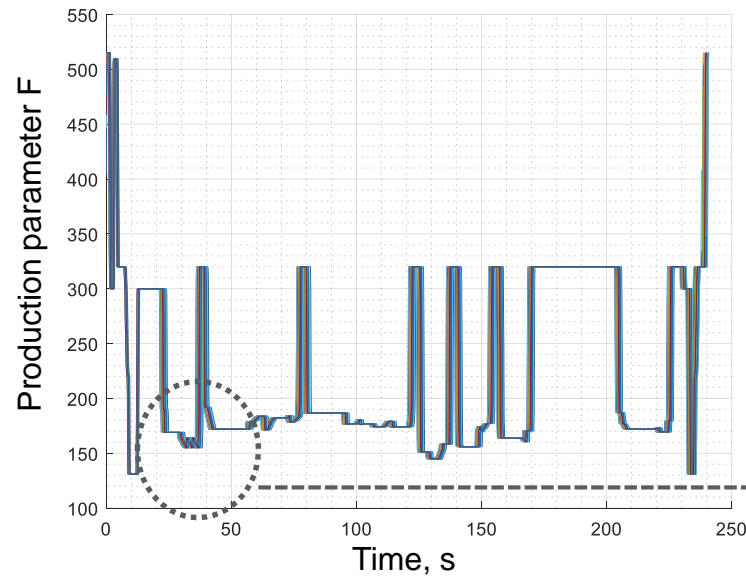
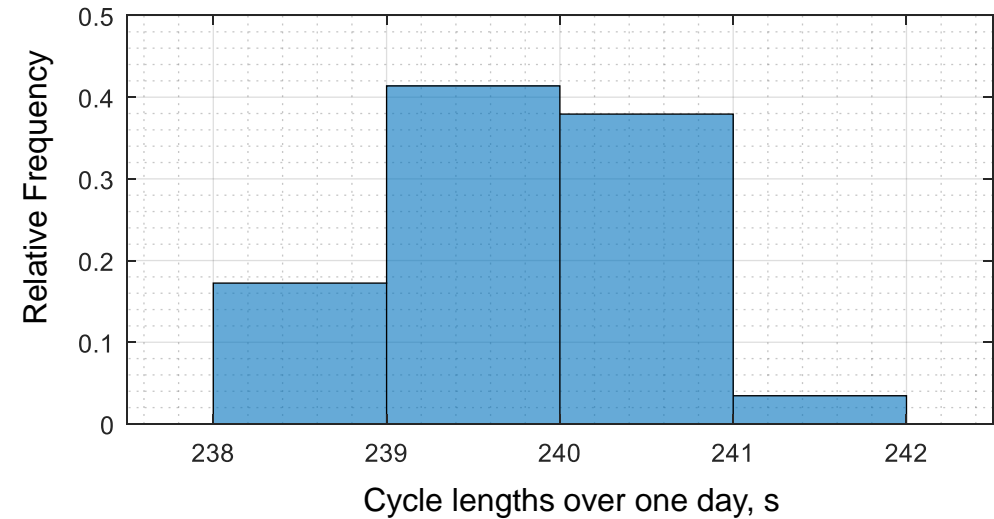
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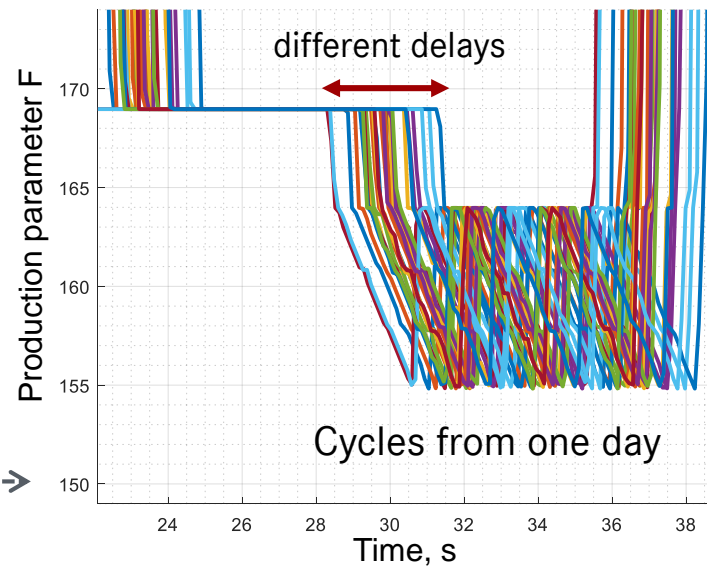
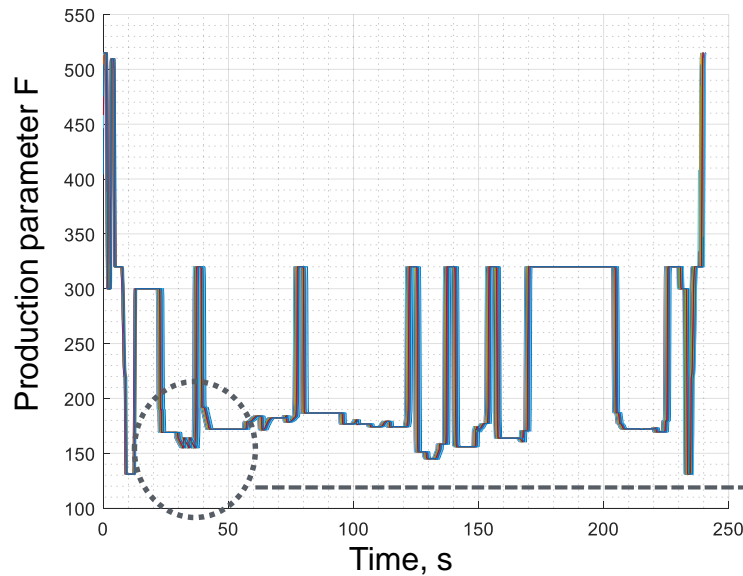
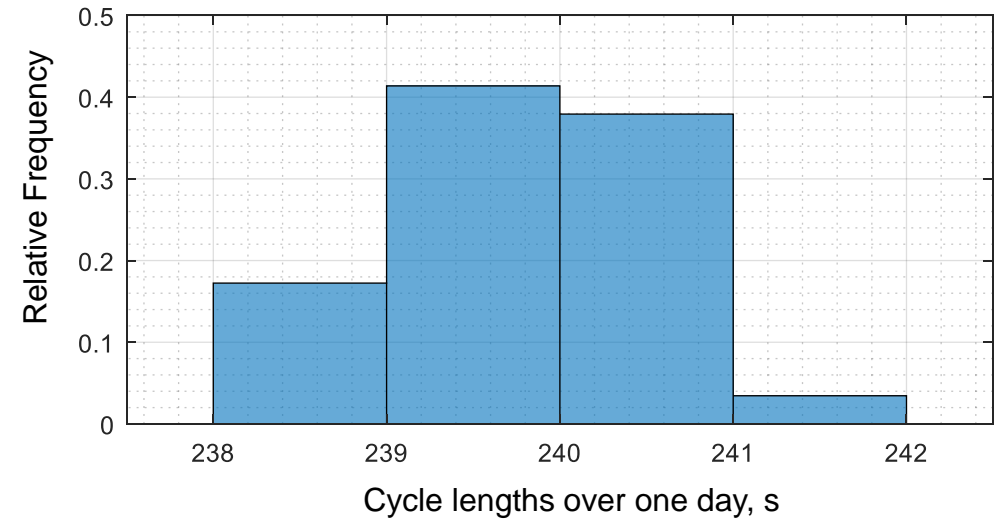
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# Delays in production cycles

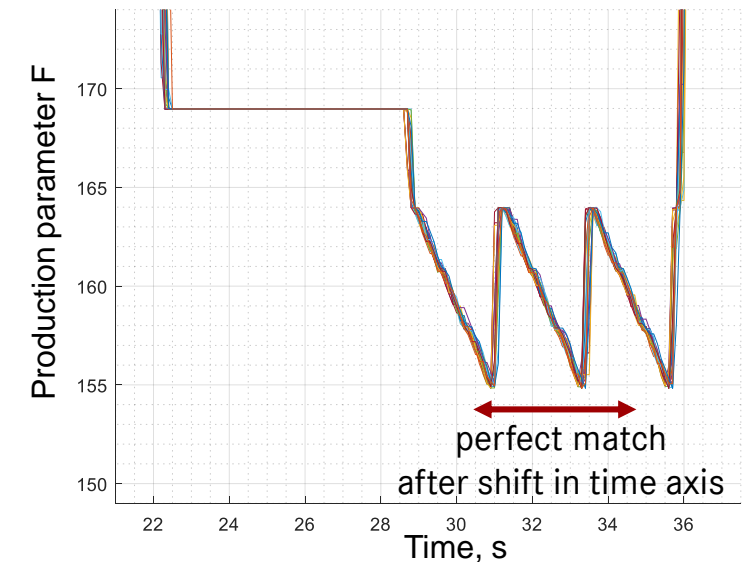
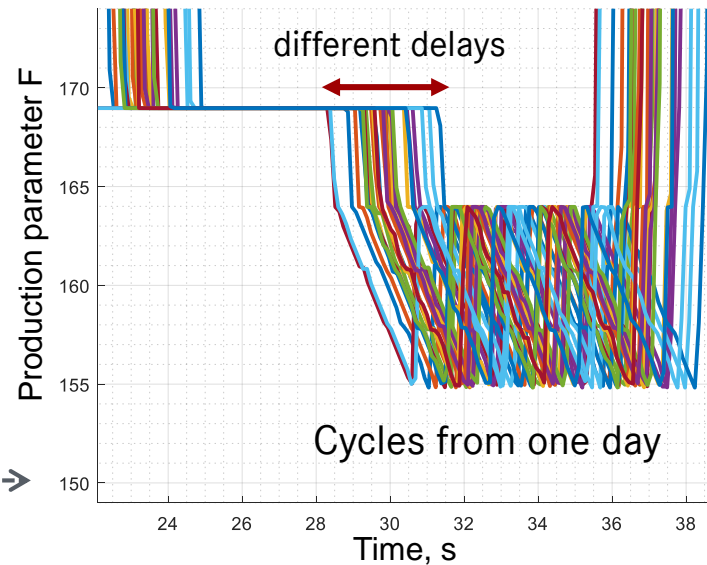
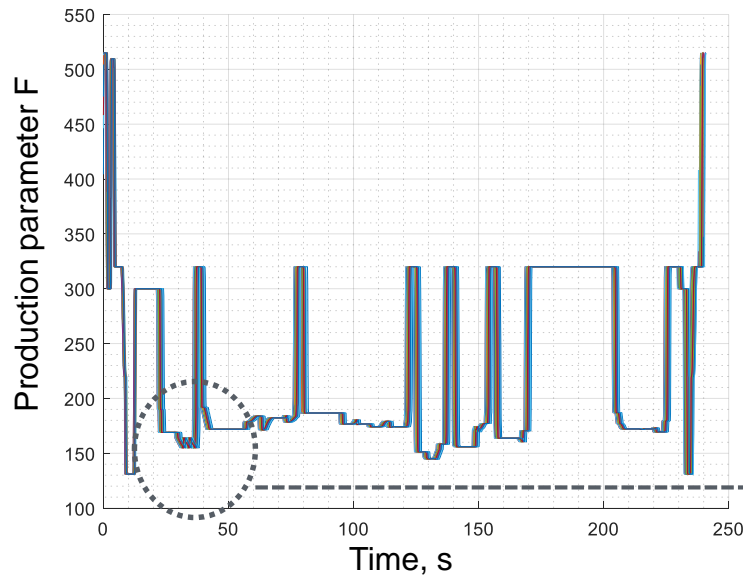
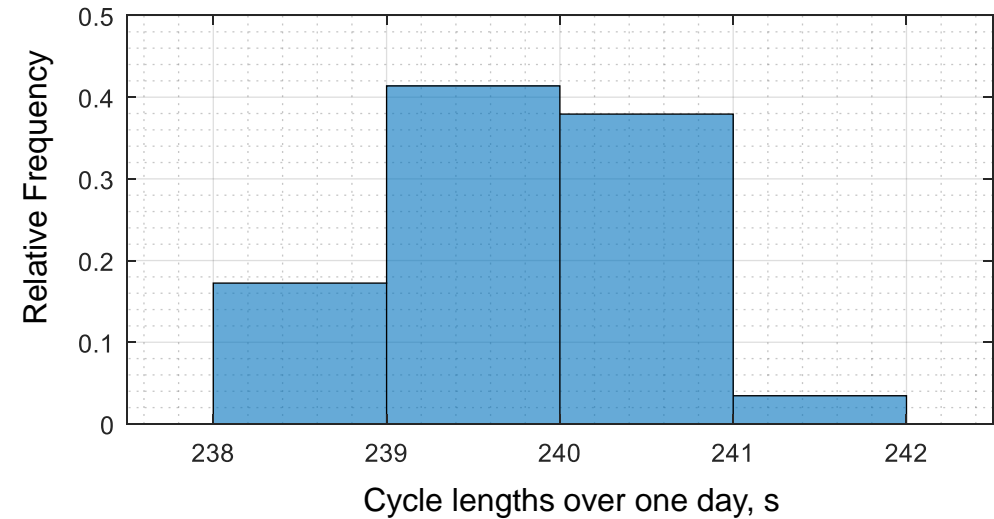
- Length of time-series varies from cycle to cycle even for normal production



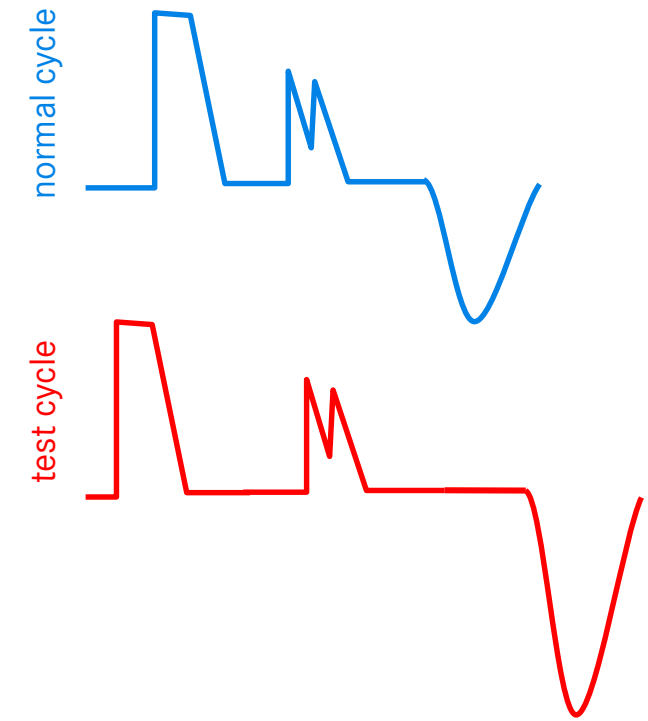
# Delays in production cycles

- Length of time-series varies from cycle to cycle even for normal production

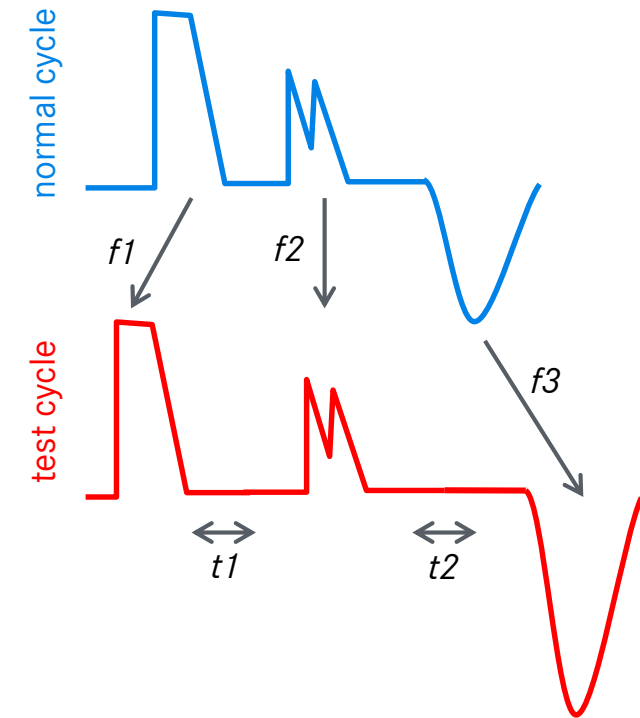
➔ Normal cycles can be matched to one another through shifting in time axis!



# Algorithm principle



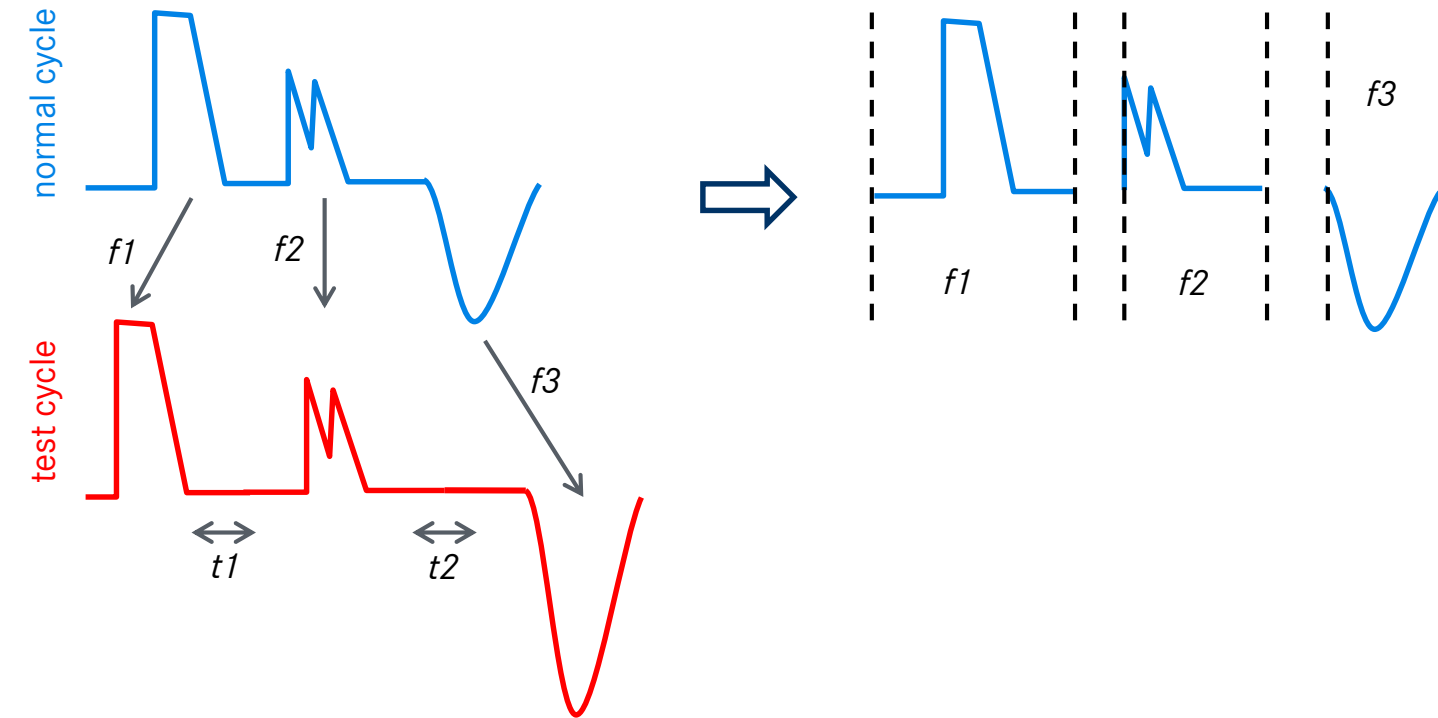
# Algorithm principle



- Cycle can be described as sequence of features  $f1$ ,  $f2$ ,  $f3$
- Each cycle can show some delays in time  $t1$ ,  $t2$

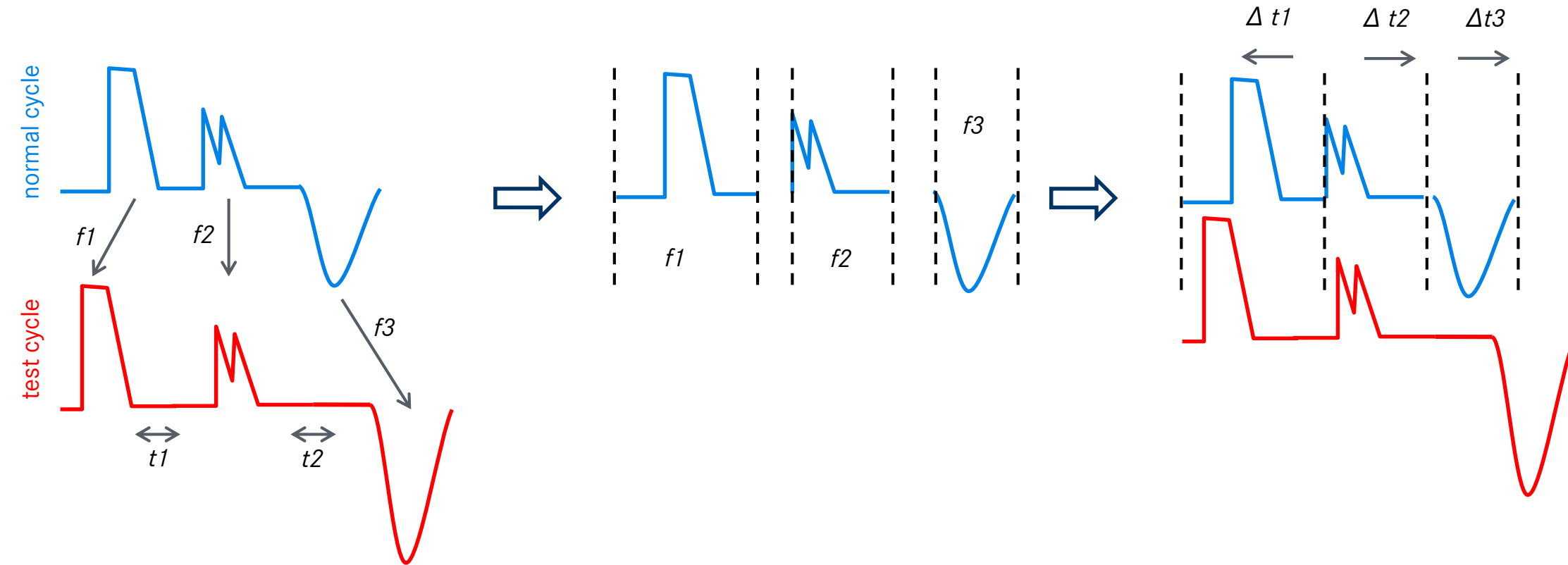


# Algorithm principle



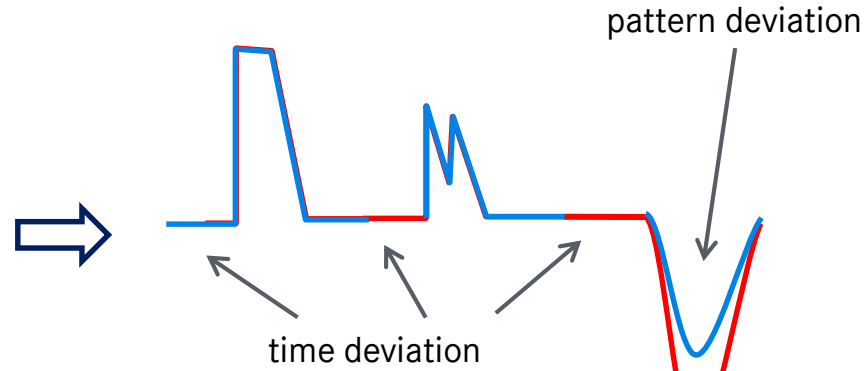
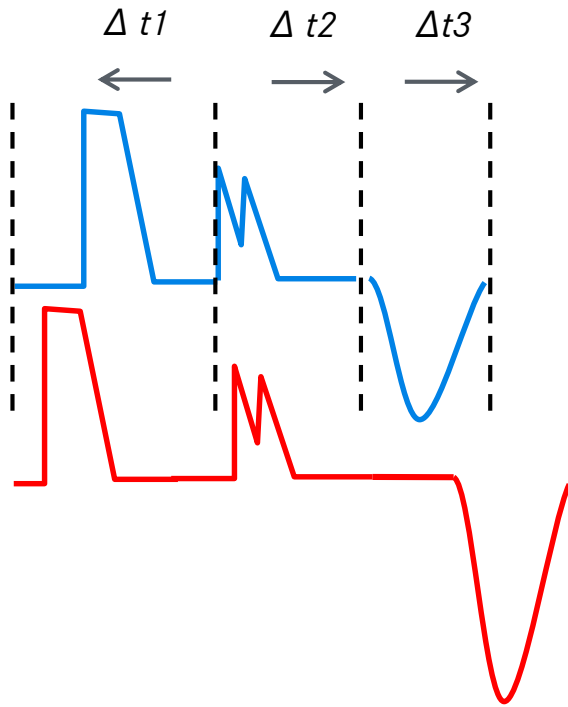
- Cycle can be described as sequence of features  $f1, f2, f3$
- Each cycle can show some delays in time  $t1, t2$
- Automatic feature detection  $f1, f2, f3$

# Algorithm principle



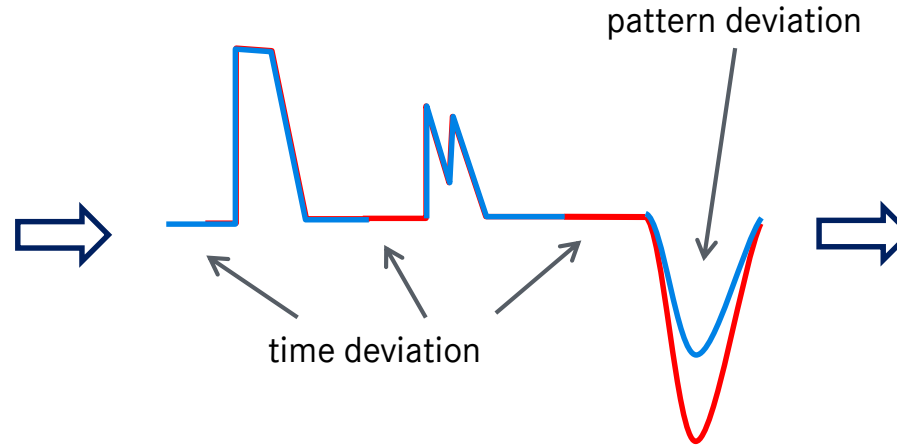
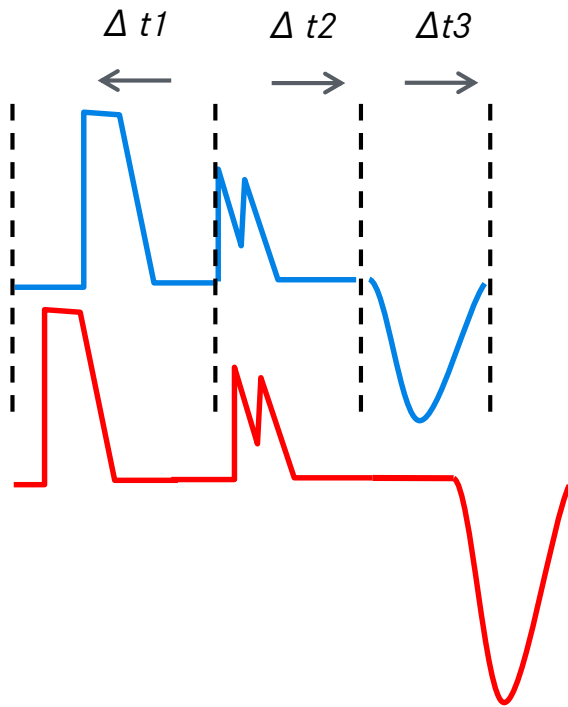
- Cycle can be described as sequence of features  $f_1, f_2, f_3$
- Each cycle can show some delays in time  $t_1, t_2$
- Automatic feature detection  $f_1, f_2, f_3$
- Pattern matching through shift of feature along time axis ( $\Delta t_1, \Delta t_2, \Delta t_3$ ): least square fit ( $t_{shift}$  to minimize the Sum of Residual Squares of two signals)

# Algorithm principle



- Pattern matching through shift of feature along time axis ( $\Delta t_2$ ,  $\Delta t_2$ ,  $\Delta t_3$ ): minimization of SRS

# Algorithm principle



$f1$	$f2$	$f3$	
$\Delta t1$	$\Delta t2$	$\Delta t3$	Time deviation
No	No	Yes	Pattern deviation

- Pattern matching through shift of feature along time axis ( $\Delta t1$ ,  $\Delta t2$ ,  $\Delta t3$ ): minimization of SRS

- Description of a cycle as feature sequence
- For each feature time and pattern deviation can be calculated

- Time and pattern deviation for each feature are used as characteristic numbers for test cycle

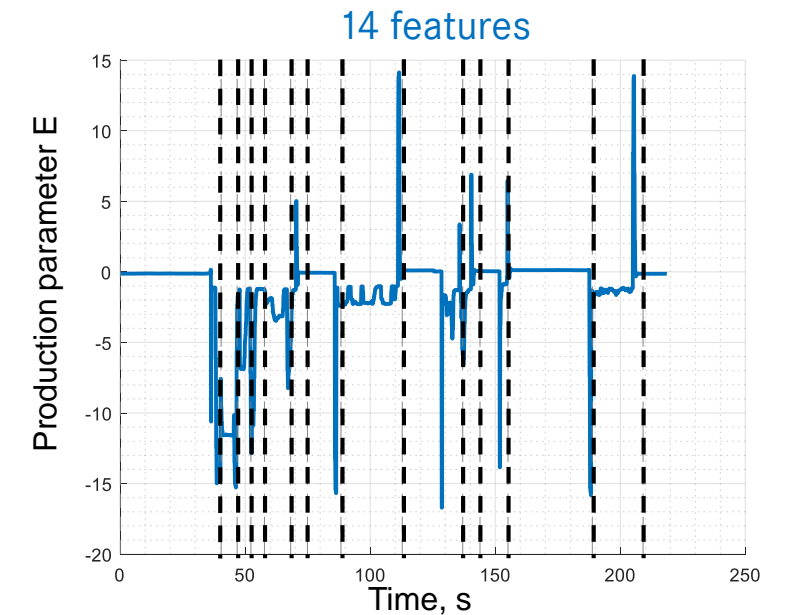
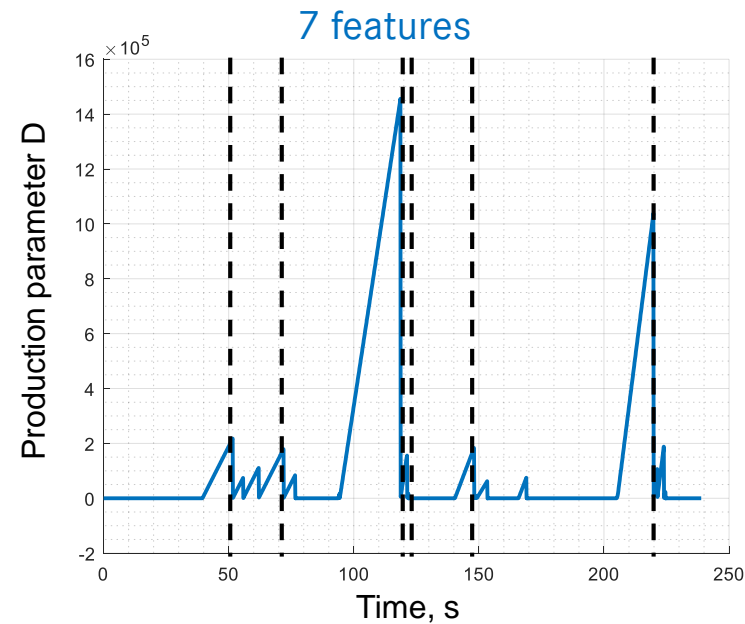
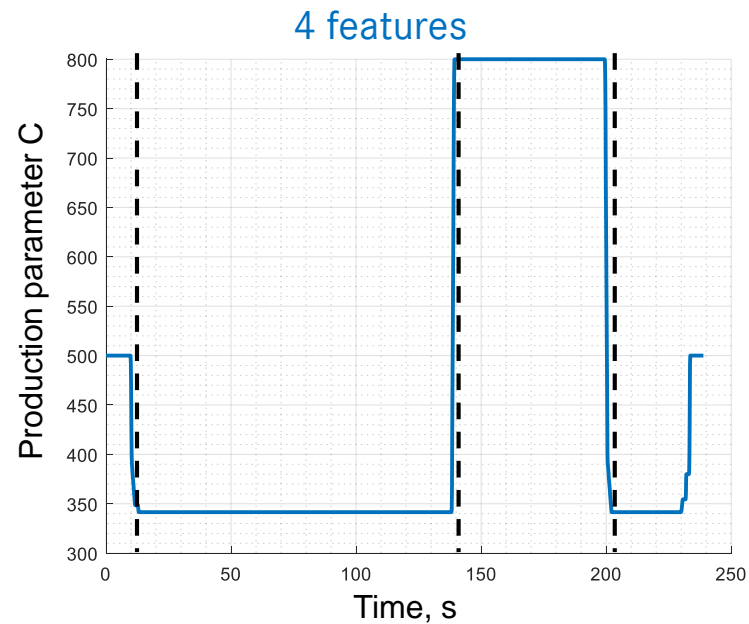


Data reduction!

# Automatic feature detection

Time series is split

- After a local extremum (maximum or minimum) or on a plateau
- After a given relative change



➔ Data reduction of time series from 2500 datapoints to sequence of max. 60 features (typically 10)!

# Algorithm implementation: machine learning approach in MATLAB



Reference cycles ->

- Build „reference signal“ for each feature
- Limits for time and pattern deviation



Test cycles ->

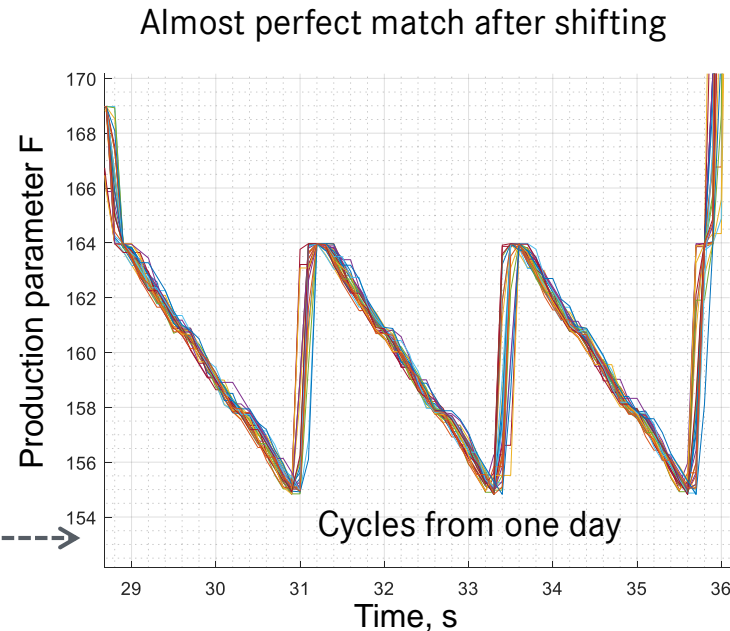
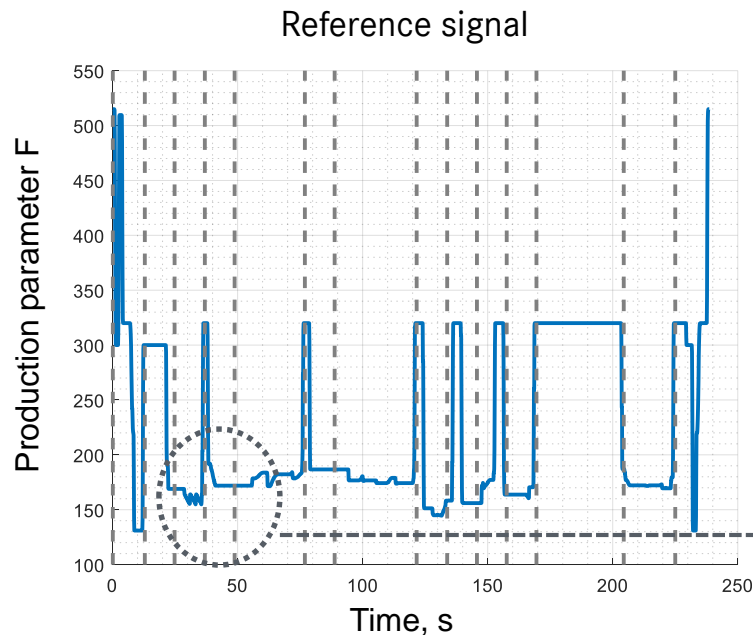
- Comparison of each feature in reference signal
- Is time and pattern deviation within the limits?

# Create „reference signal“ for each production parameter



Training

1. For all training cycles - matching to shortest cycle
2. Create „reference signal“ – mean over all matched reference cycles

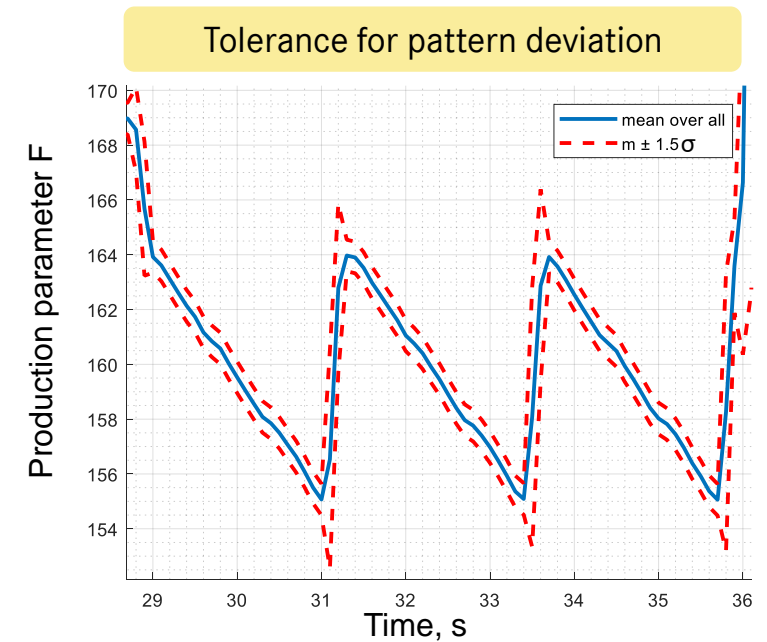
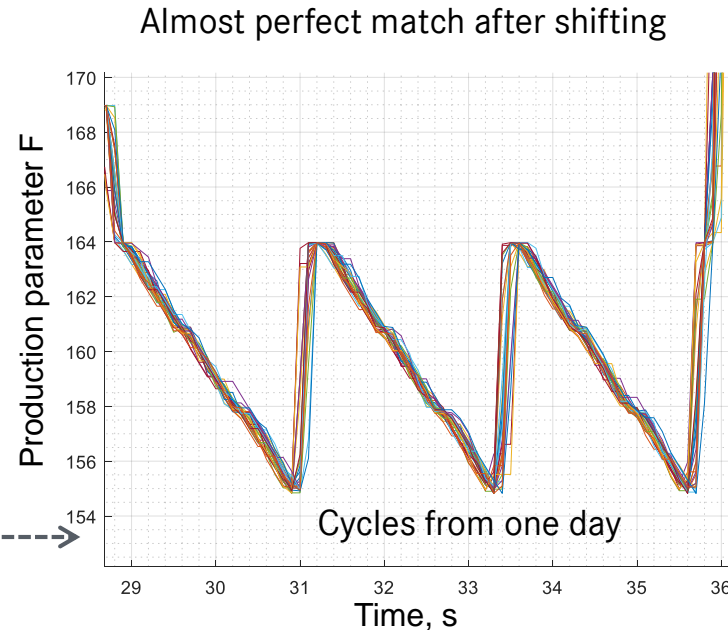
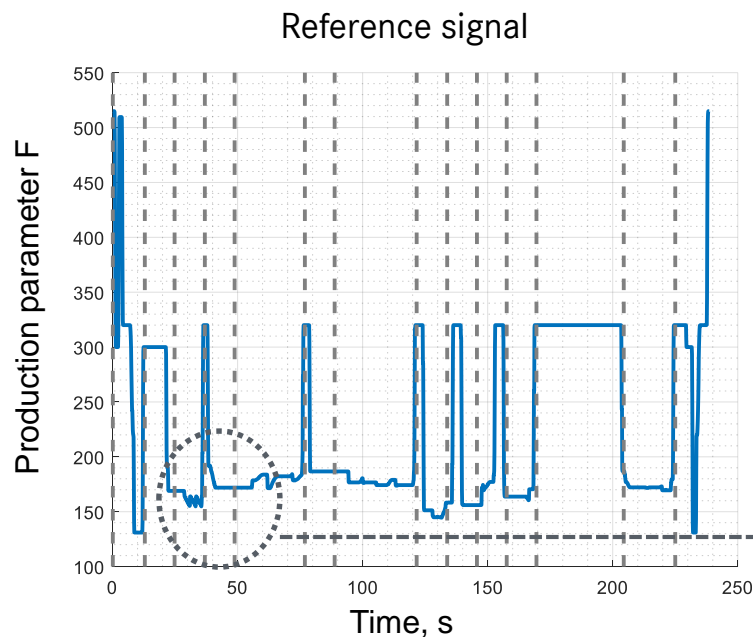


# Create „reference signal“ for each production parameter



Training

1. For all training cycles - matching to shortest cycle
2. Create „reference signal“ – mean over all matched reference cycles
3. Possible pattern deviation - standard deviation over all matched reference cycles





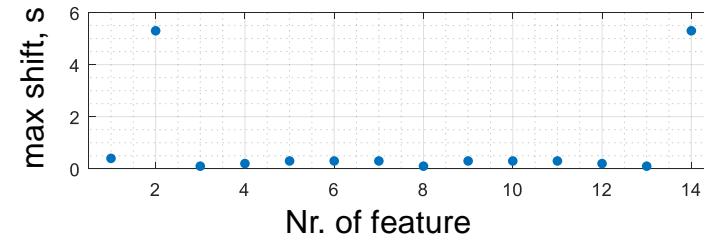
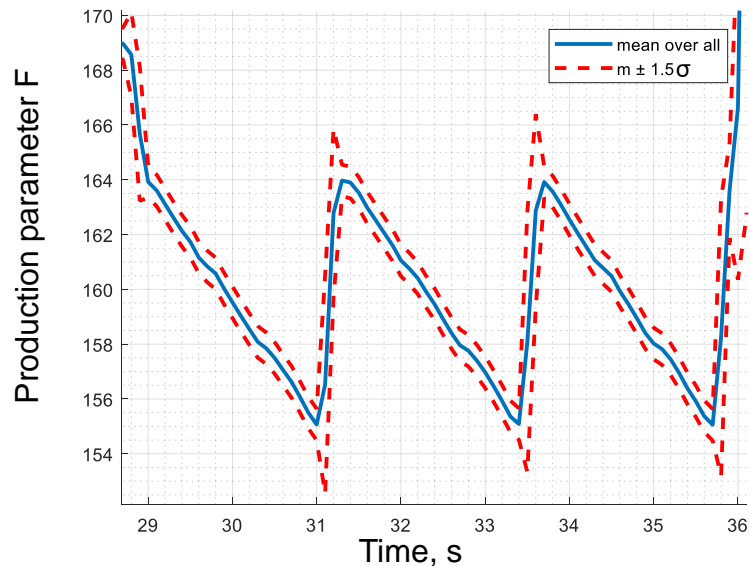
# Create „reference signal“ for each production parameter



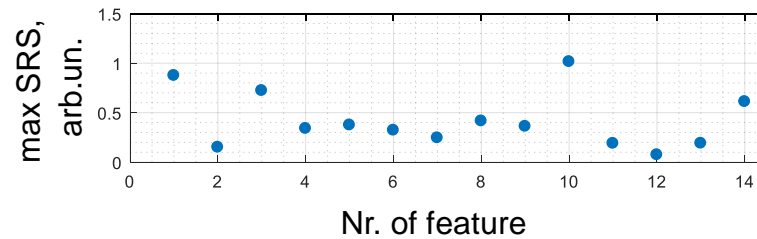
Training

1. Create „reference signal“ – mean over all matched reference cycles
2. Possible pattern deviation - standard deviation over all matched reference cycles, limits for SRS
3. Possible time deviation – maximal absolute shift from matched reference cycles

Tolerance for pattern deviation



Possible time deviation

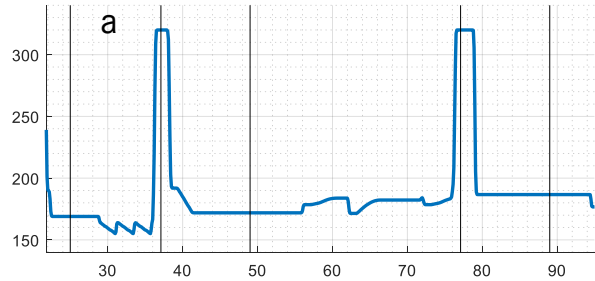


Possible pattern deviation

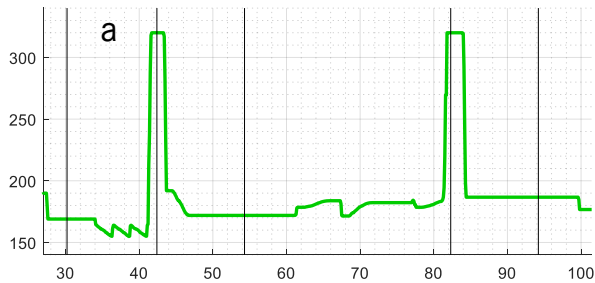
# Testing: time and pattern deviation evaluation



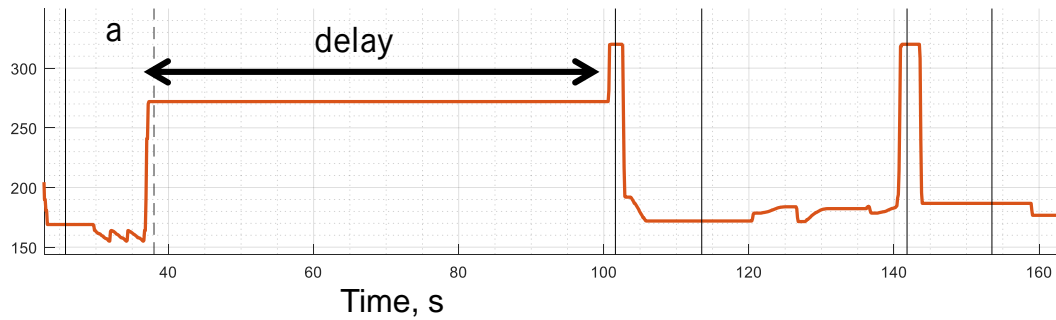
reference signal



normal cycle



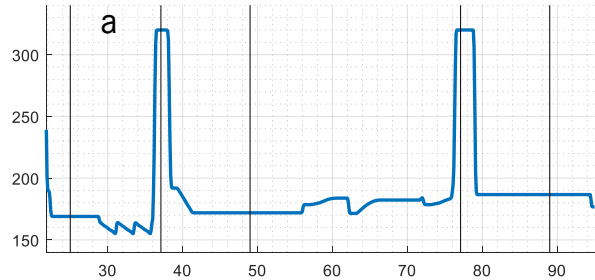
error cycle



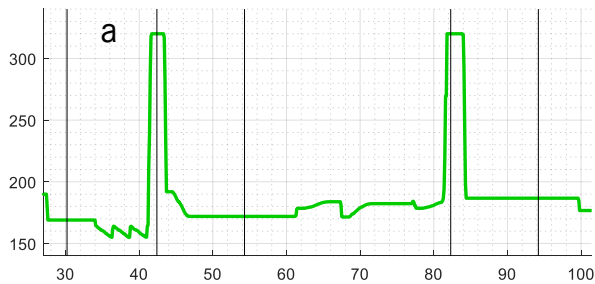
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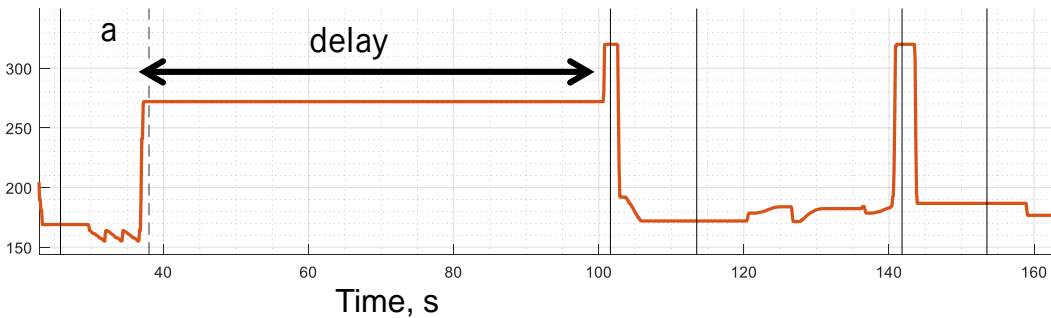
reference signal



normal cycle

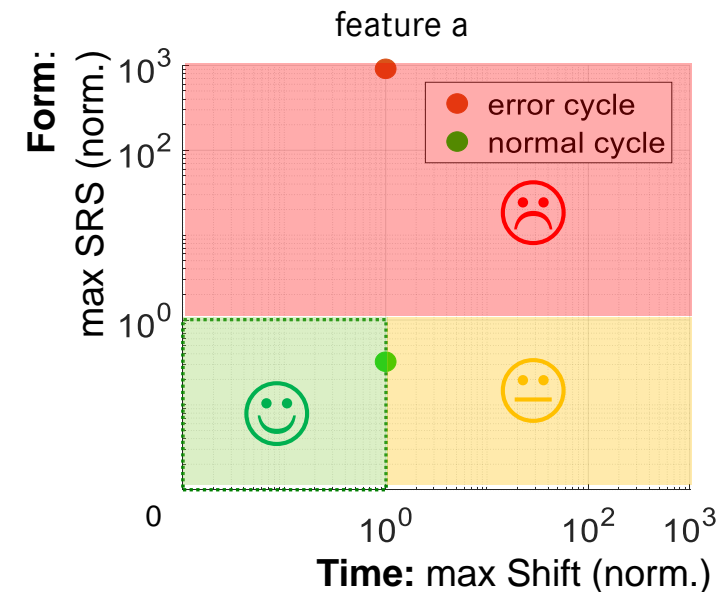


error cycle



Is time and pattern deviation for this feature within the limits?

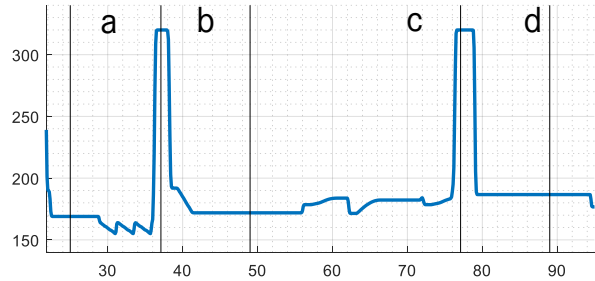
- Tolerance window ( $\Delta t$ , *SRS*)
- Easy to spot a critical deviation



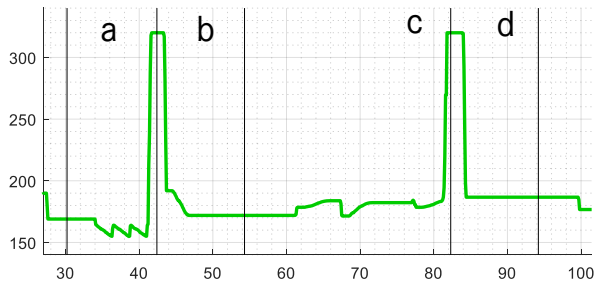
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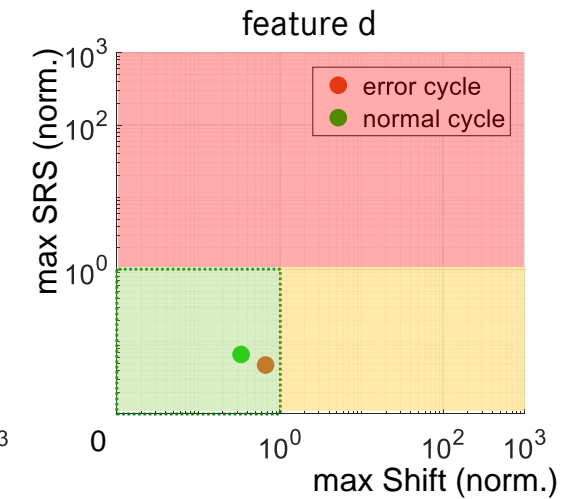
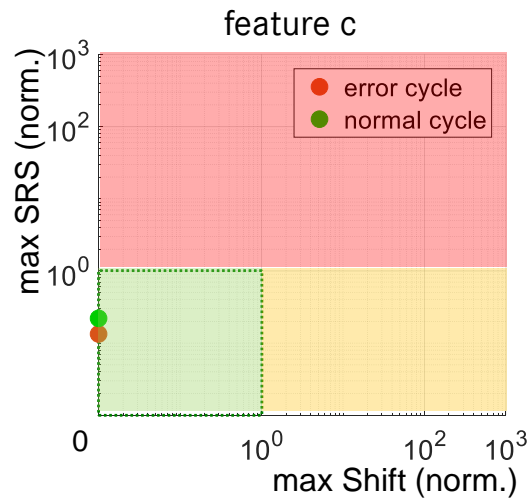
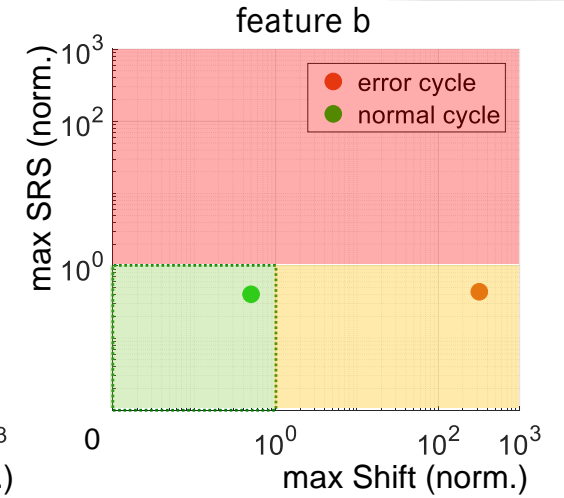
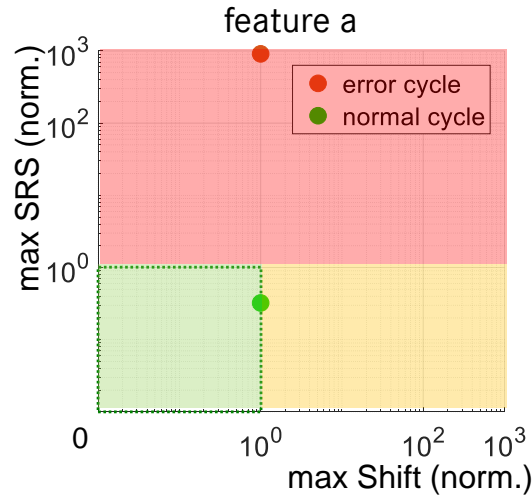
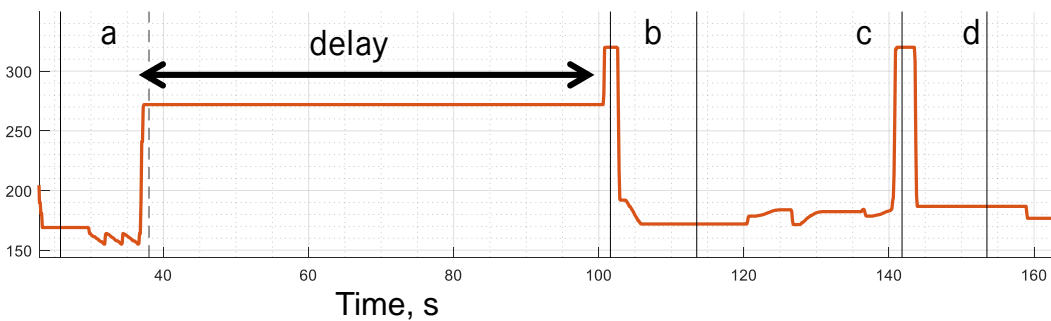
reference signal



normal cycle



error cycle



# Algorithm: Summary

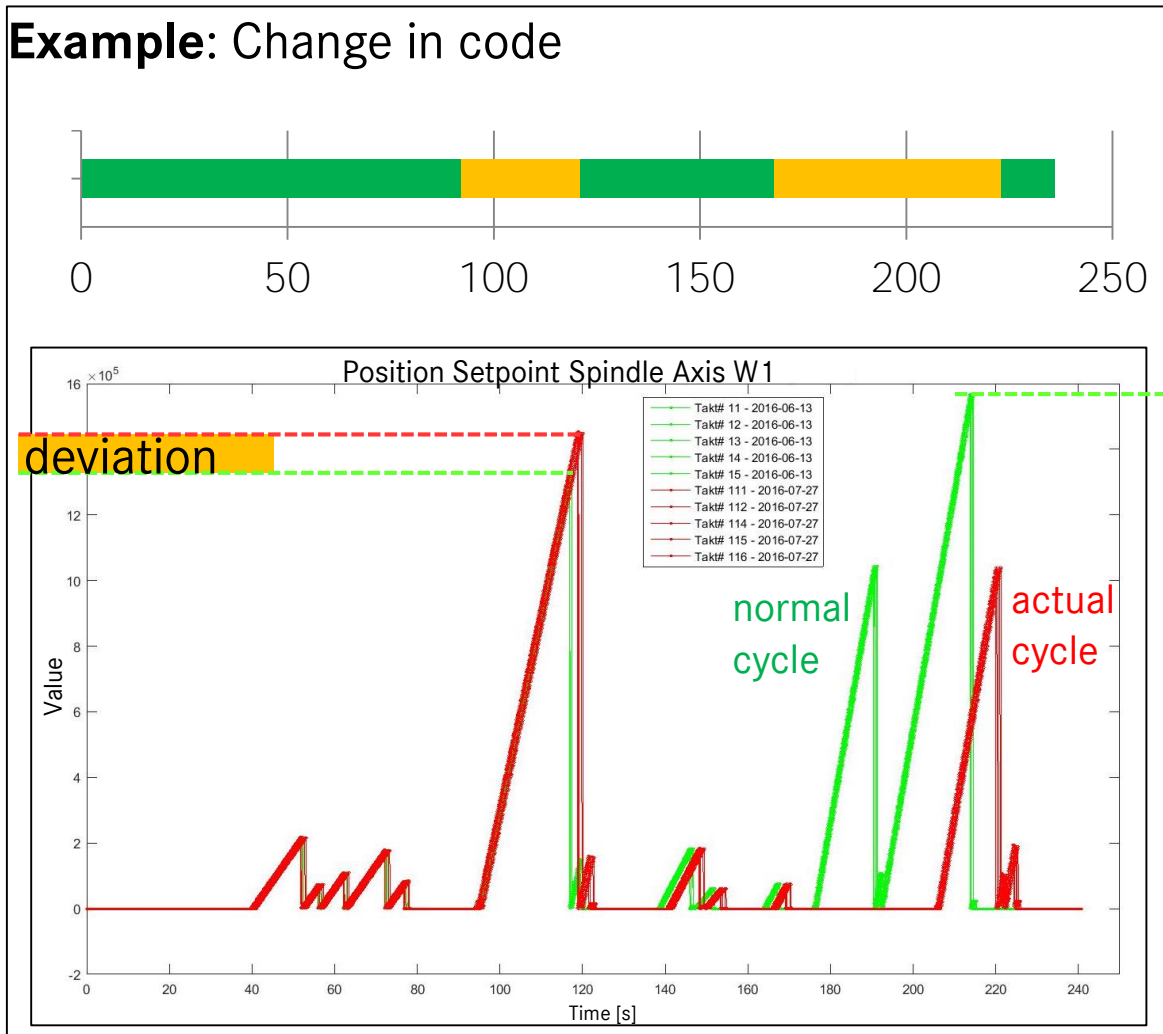
1. Quantitative and qualitative description of production failure
2. Independent of signal form -> universally applicable to other applications or machines
3. Signal description with characteristic numbers, which are easy to interpret
4. Data reduction with a factor **250** without significant loss of information!
5. Easy control of production: recognition of critical errors and non-critical delays online

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# Example of the added value



## Example: Change in code



## Results:

- Transparency of the process
  - Deviation for each Signal
  - Reason of Cycletime increase found
- ➔ Time and Pattern deviation are recognized

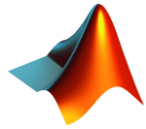
# Summary



Algorithm using pattern matching for time series developed and implemented for production data

## Why MATLAB?

- easy algorithm implementation
- existing solution for data import
- very good support and broad use in universities



## MathWorks products used:

- Signal Processing Toolbox
- Statistics and Machine Learning Toolbox

## Outlook:

- Parallel Computing Toolbox for performance improvement



Prototyp intelligent Level-Learning (iLL)  has a new function for anomaly detection

- Troubleshooting in case of failure (maintenance), Parts Planning, Influences on the quality  
→ Optimization of repair time, spreaders amount, ...

Thank you for your attention!



Mercedes-Benz

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The logo for Dr. Türck Data Science features a stylized 'D' shape composed of a blue semi-circle on the left and a yellow semi-circle on the right.

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