Drill-down Analysis with Equipment Health Monitoring

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Outline

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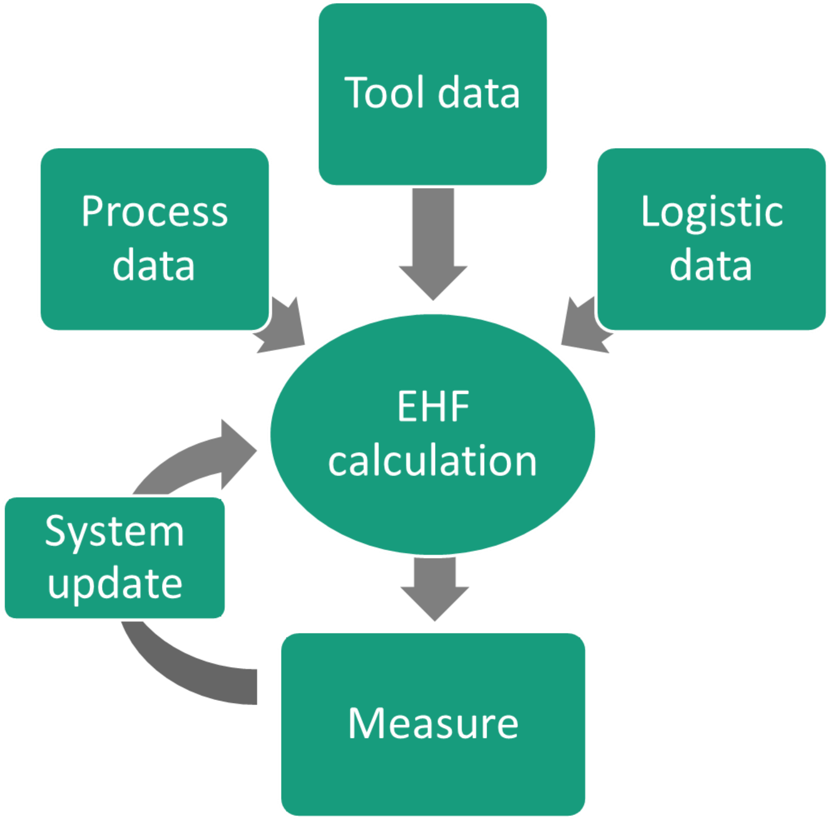
I. Motivation

Definition: Equipment health factor

- Key indicator for monitoring of equipment state
- Based on process/tool, logistic and metrology data
- Utilization of historical data for training of EHF system
- Related key words
    - Equipment health monitoring
    - Equipment fingerprinting
    - Health index
    - EHF



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Goal of the determining EHF is to enable…

- **Dynamic Sampling**

  Sampling rate is flexible and adjusted to the machine state.

- **Material flow of critical products**

  The production of critical products (important customers lots, urgent jobs, etc.) is planned only on machines which have a good system state.

- **Predictive Maintenance (PdM) based on condition monitoring**

  The PdM offers cost savings over time-based preventive maintenance, because maintenance actions are performed only when necessary.

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Application of the EHF

- Good machine state – EHF is high
  - → Lower lot sampling rate, important lots will preferably be scheduled to run on this machine
- Machine state not ideal – EHF decreases
  - → More frequent lot sampling, important lots might be scheduled to run on another tool
- "bad" machine state – EHF drops below certain limit
  - → Schedule maintenance

Related work

- Utilization of sensors for simple measurement of wear
- Detection of failures based on key indicators
- Usually only implemented for specific failure classes
- No general method for detection of unknown failures

- **Our objective:**
  - Improved preprocessing method to find unknown failures
  - Use of various feature extraction methods dependent on curve shape
  - Express the current equipment condition
  - Generic concept transferable to other processes

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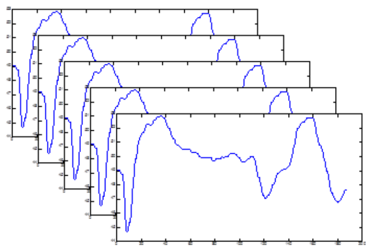
II. Feature extraction procedure

Classification of curve shape



Process variable (time series)

→

- Oscillating behavior
- Piecewise-constant
- Spike behavior
- Smooth behavior

Classification of curve shape

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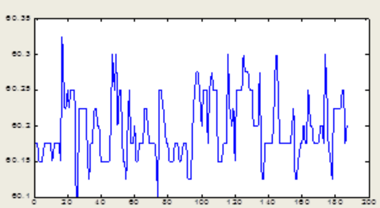
Defined variable types

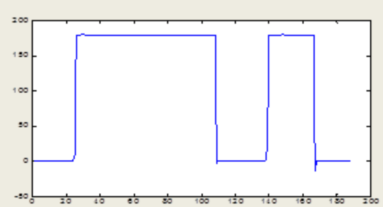
- **Oscillating behavior:** trajectories with periodic variation around a central value
- **Piecewise-constant:** rectangular shaped pulses
- **Spike behavior:** most data points are close to zero with occasional peaks
- **Smooth behavior:** data with little change in their point to point value, the derivation showing only small differences in the gradient

Oscillating behavior



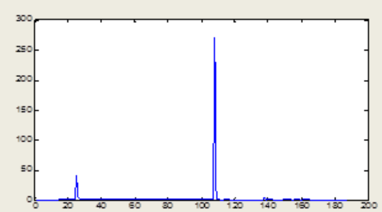
e.g. chamber temperature

Piecewise-constant



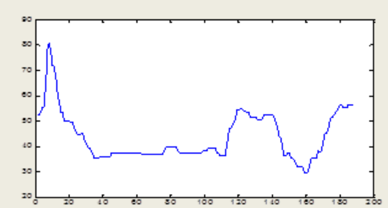
e.g. gas flows

Spike behavior



e.g. reflected RF power

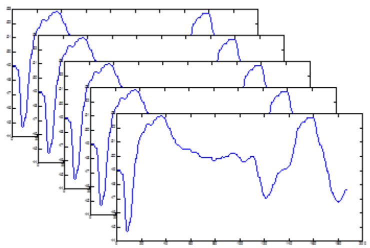
Smooth behavior



e.g. ESC temperature values

II. Feature extraction procedure

Feature extraction method



Process variable (time series)

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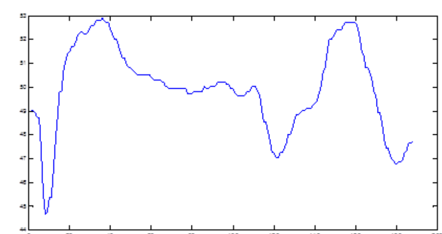
Classification of curve shape



e.g. regression coefficients

Feature extraction method

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Types of feature extraction

- **Simple key features**
  - Mean, median, standard deviation and range
- **Structural features**
  - Descriptive statistics of trajectories
- **Dynamic time warping**
  - Euclidean-distance-based similarity measurement technique
- **Frequency and time-frequency analysis**
  - Analysis in frequency domain instead time domain
- **Statistical analytical methods**
  - e.g. regression coefficients or residual analysis

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Extracted features

Oscillating behavior
- Periodicity
- Trend
- Simple key features

Piecewise-constant
- Number of pulses
- Amount of Under-/Overshoots
- Maximum Overshoot
- Area under a pulse

Spike behavior
- Number of peaks
- Peak width
- Area under a peak
- Distance of peaks

Smooth behavior
- Wavelet-based correlation coefficient
- Root mean square of residuals
- Area under curve

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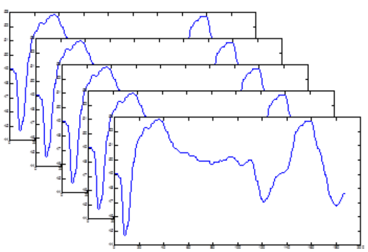
II. Feature extraction procedure

Computation of scalar key values



Process variable (time series)

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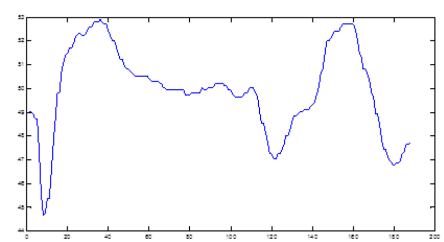
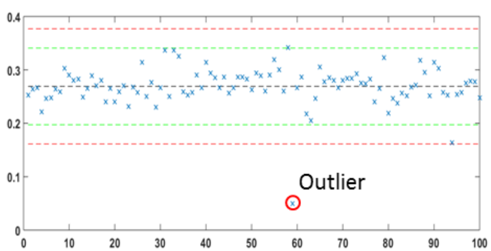
Classification of curve shape



e.g. regression coefficients

Feature extraction method



Scalar key values for EHF calculation

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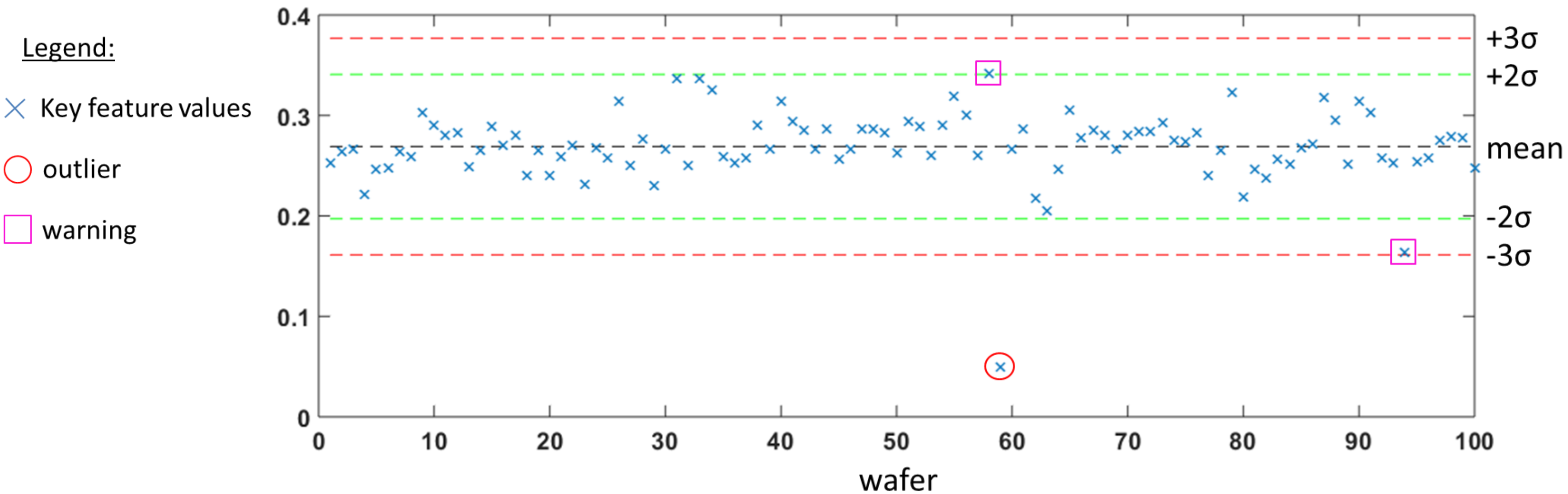
Feature factor

From feature values to scalar key value

- Feature factor is a scalar value between one and zero and reflects the state of a considered key feature in a specific time window
- Computation is based on the statistical process control (SPC)
- $$Feature\ factor = 1 - \frac{0{,}01 \times Warnings \times 100}{Number\ of\ Samples} - \frac{0{,}1 \times Outliers\ \times 100}{Number\ of\ Samples} = 0{,}88$$



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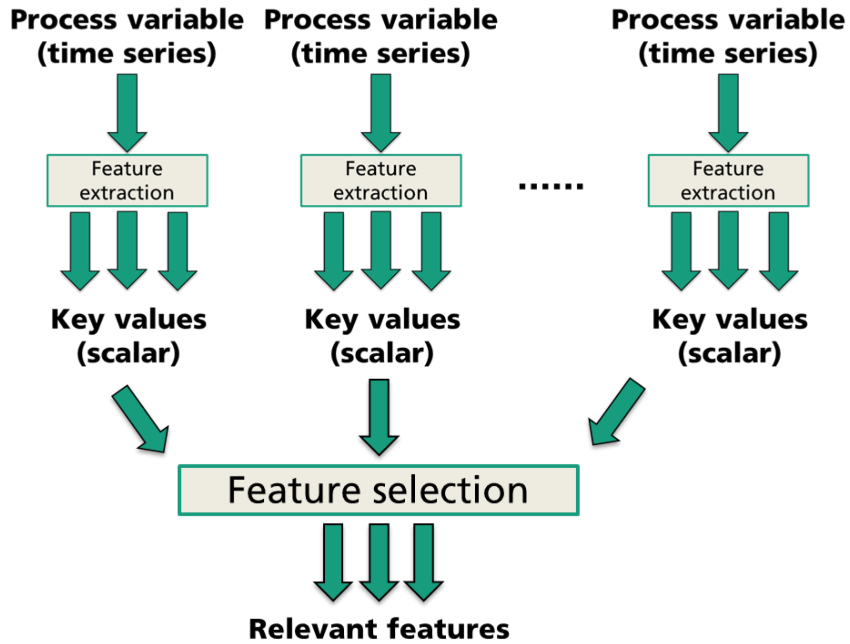
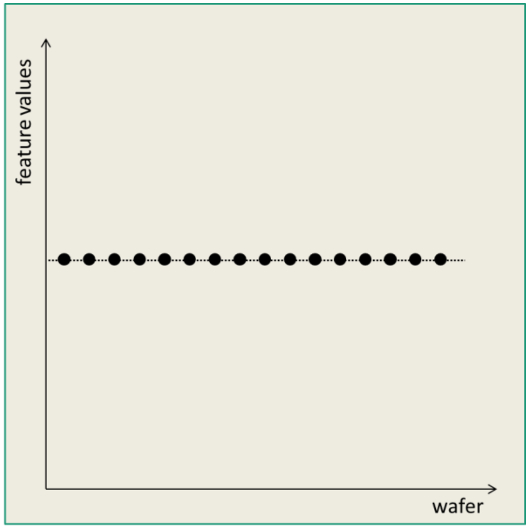
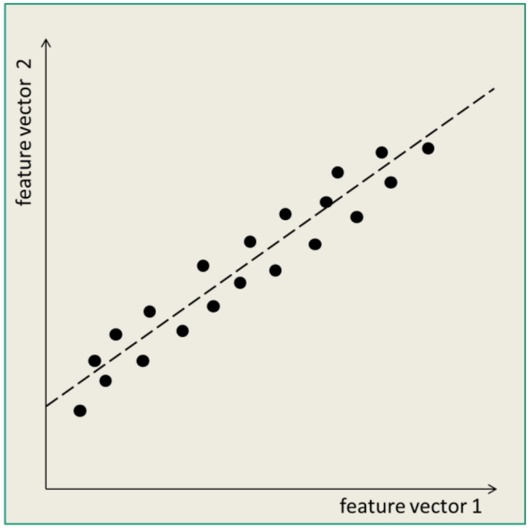
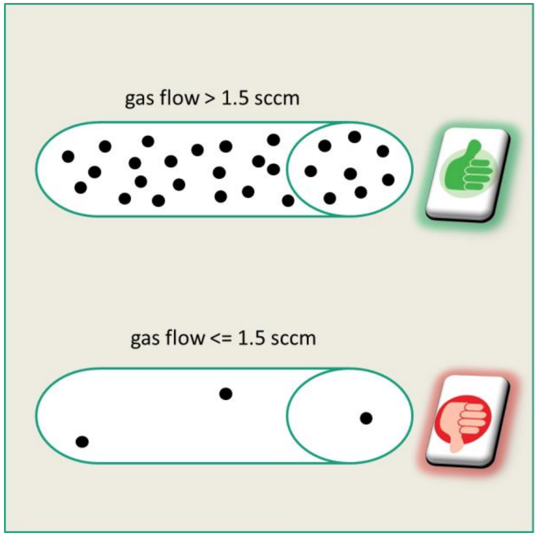
III. Feature selection



Selection criteria

Invariant feature vector	*feature vectors |r| >= 0.85*	*gas flow <= 1.5 sccm*
		
feature vector is excluded	only one feature vector is considered	feature vector is excluded

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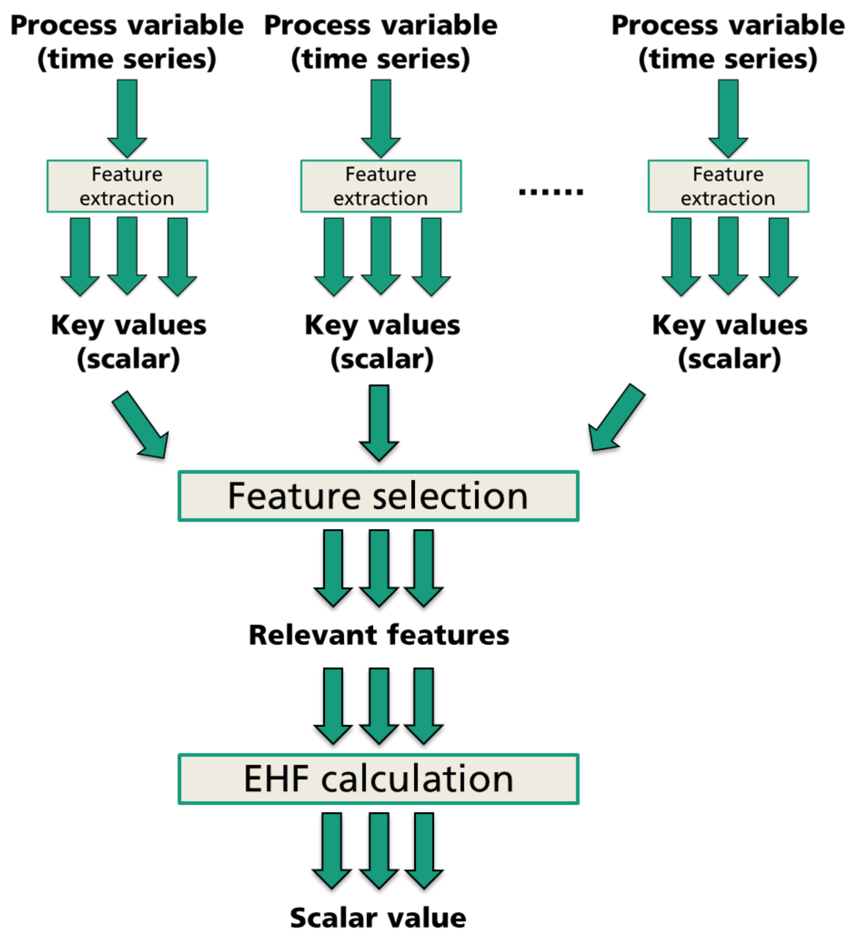
IV. EHF calculation



Former approaches to calculate an EHF

- EHF as output of the averaging of all relevant parameters:

$$\frac{\text{Feature Factor} + \text{Feature Factor} + \text{Feature Factor} + \ldots + \text{Feature Factor}}{\text{Number of Feature Factors}} \times 100$$

- EHF by multiplying all characteristic values:

$$\text{Feature Factor} \times \text{Feature Factor} \times \text{Feature Factor} \times \ldots \times \text{Feature Factor}$$

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Comparison of former EHF calculation options

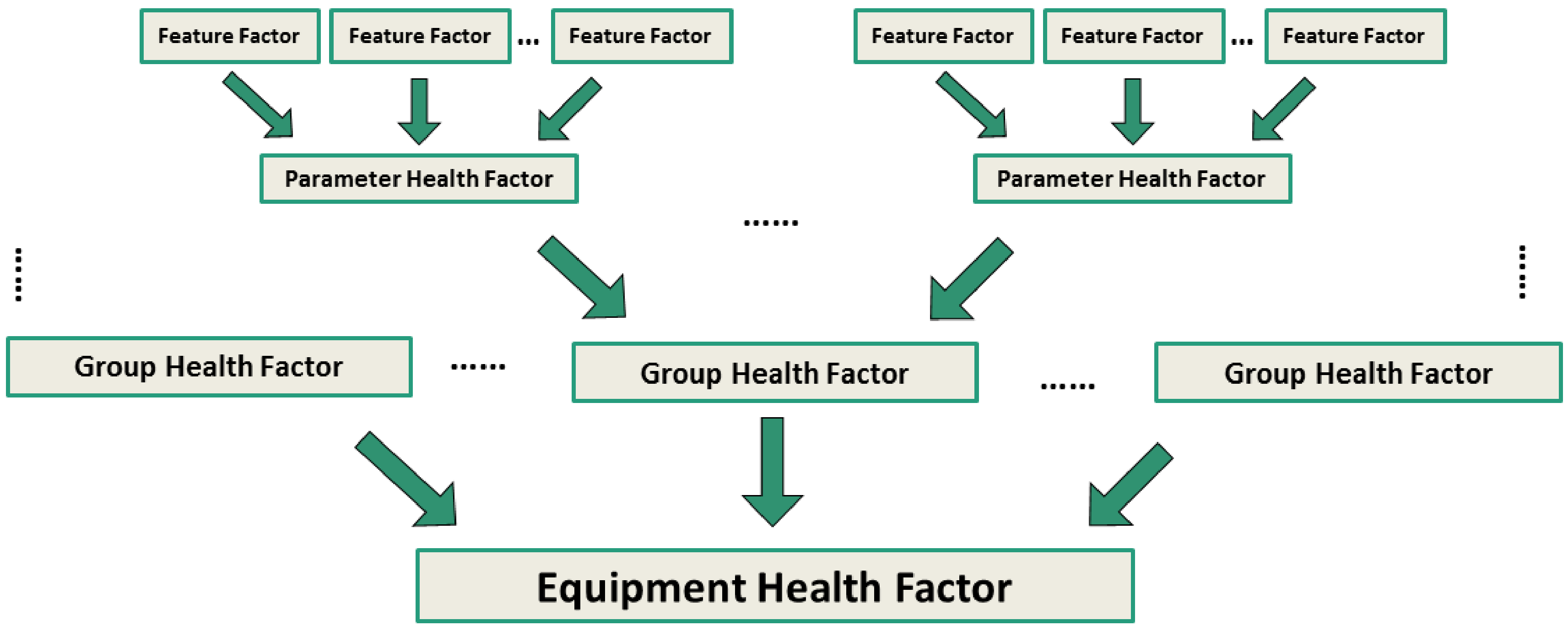
EHF as average

- Average tool state is depicted
- Bad parameters can not be detected easily
- The system status will not be set to zero even though one of the key features is beneath the wear limit
- Easier decision making whether the equipment meets the requirements or not

EHF as multiplication

- Average machine state is not identifiable
- If only one factor is equal zero the whole EHF is set to zero
- Difficult to interpret by a high amount of key features → EHF is close to zero

New EHF calculation structure



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Characteristics of the new calculation method

- Averaging takes place at three levels:
  - Parameter level
  - Group level
  - Equipment level
- Drill-down ability through intermediate steps for root cause analysis
- “Bad” parameters can be detected at a glance without huge process knowledge
- Machine state average can be obtained
- EHF result is easier to interpret

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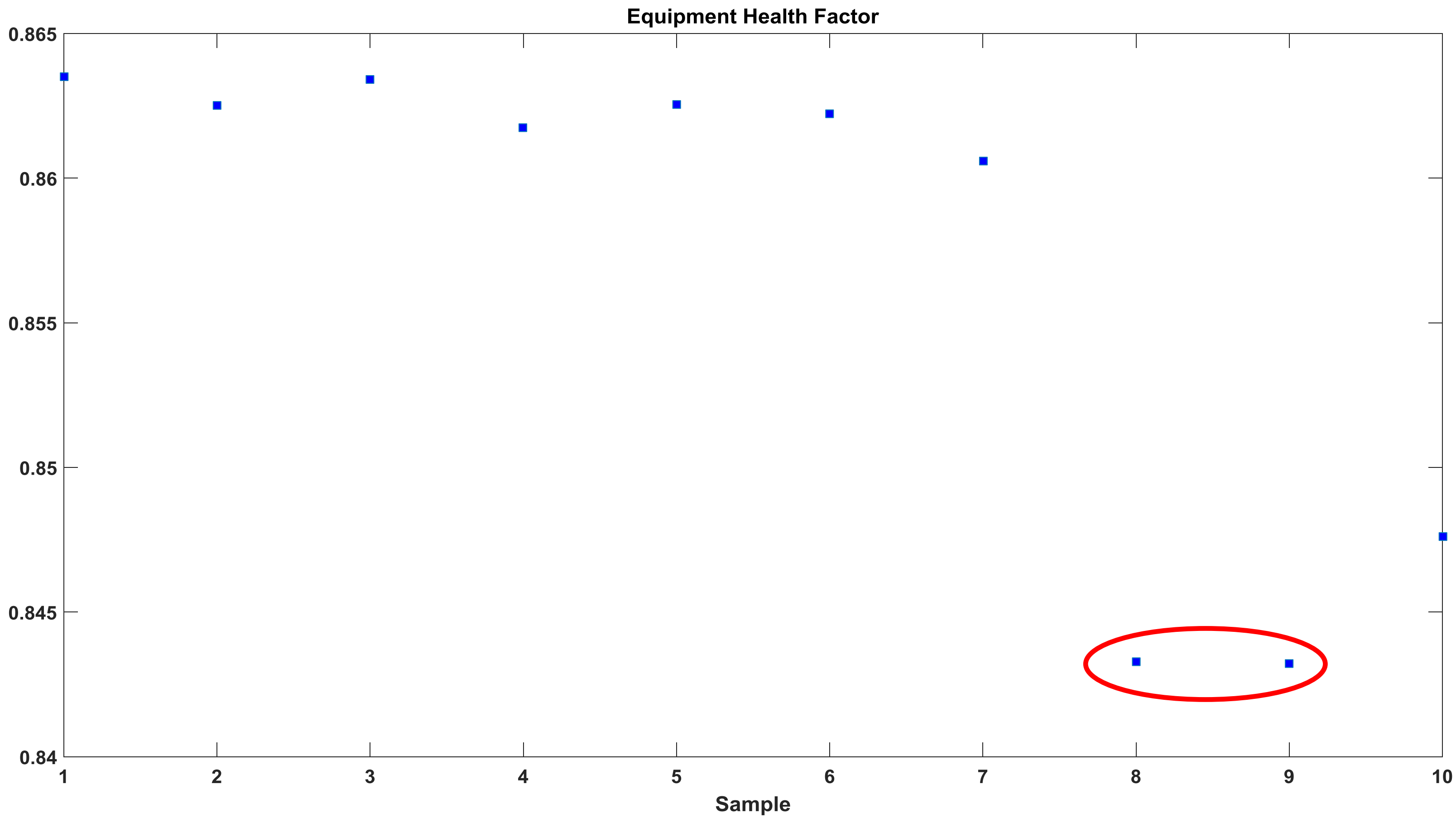
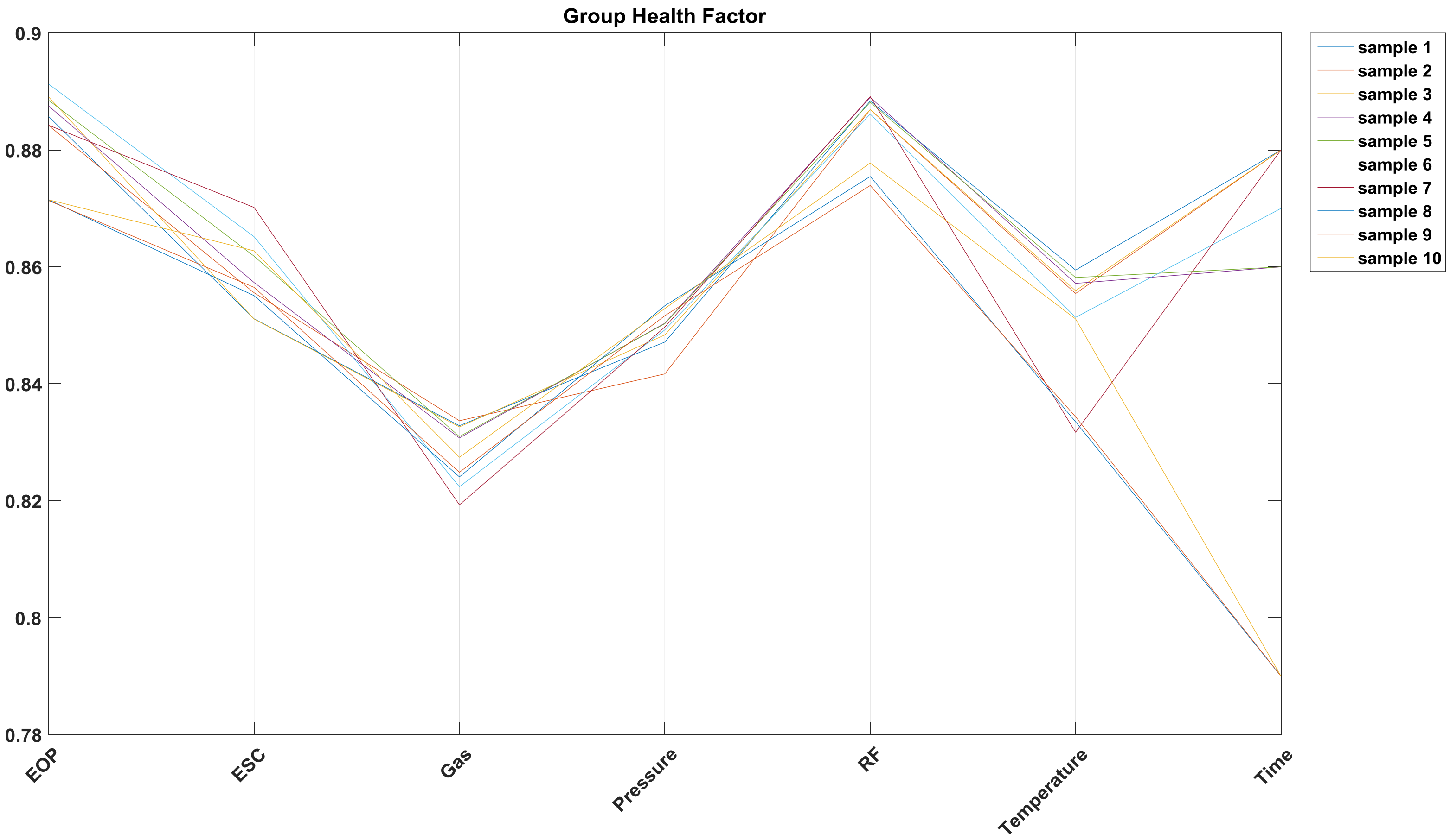
V. Application example
Equipment health factor level



V. Application example

Group health factor level



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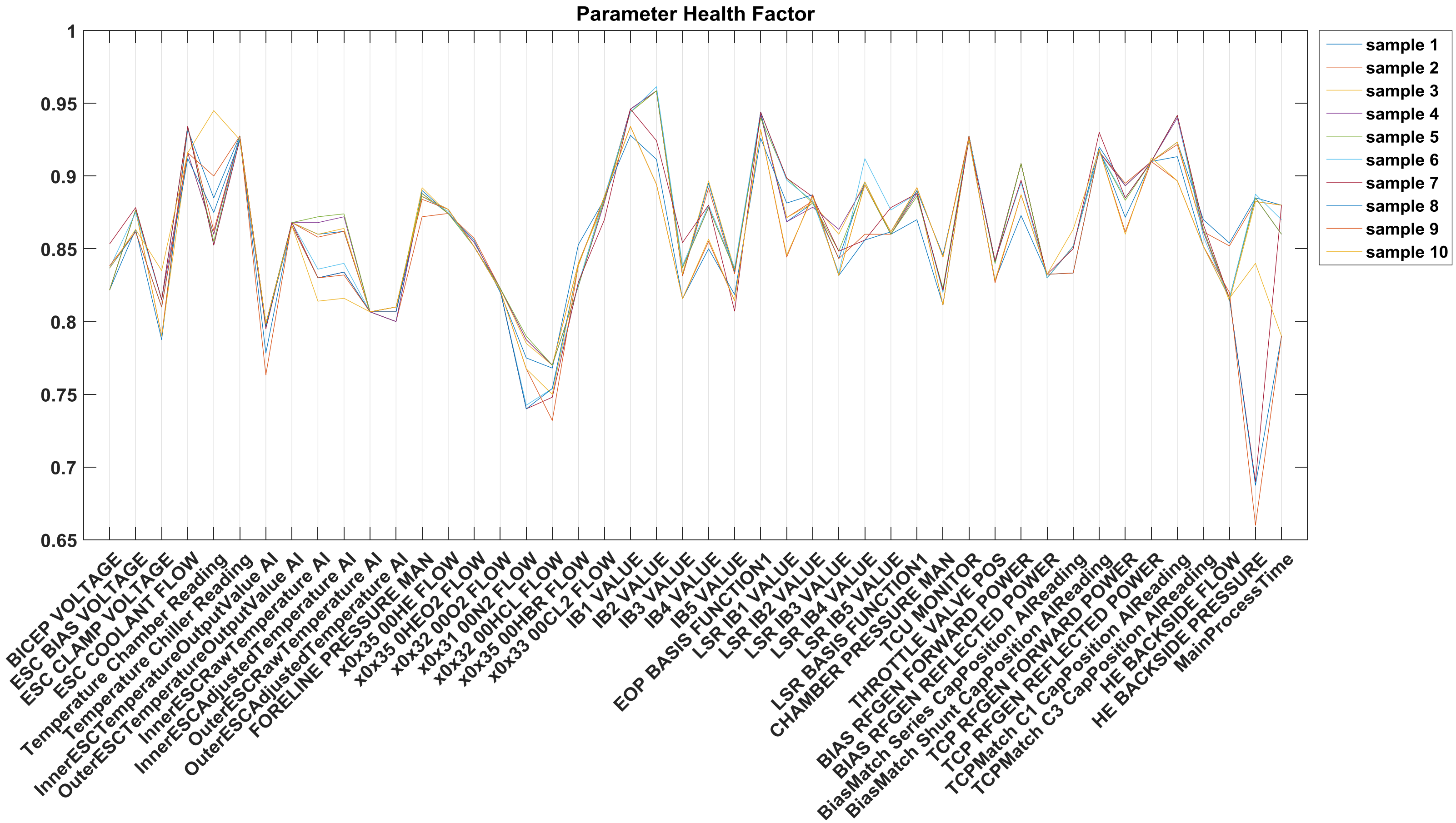
V. Application example

Parameter health factor level



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VI. Conclusion

- A general method for detection of unknown failures was developed
- Generic concept transferable to other processes
- Application of various feature extraction methods dependent on curve shape
- Extracted key features can be used for EHF calculation or other technologies to improve models
- Drill-down structure identifies underperforming components
- Desired benefit of EHF
    - Lower production costs
    - Improve production quality
    - Maintaining high yield

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Acknowledgment

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- Project work-package partners:
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  - Infineon Technologies Austria AG
  - Infineon Technologies Dresden GmbH
  - SpeedUp Consulting

Thank you for listening!