Application of Predictive Maintenance for semiconductor manufacturing equipment

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Agenda

- Concept of PdM: Overview and benefits
- Definition of Predictive Maintenance
  - Other industrial branches
  - Semiconductor manufacturing
- PdM implementation approaches
- Prerequisites for PdM
- Example

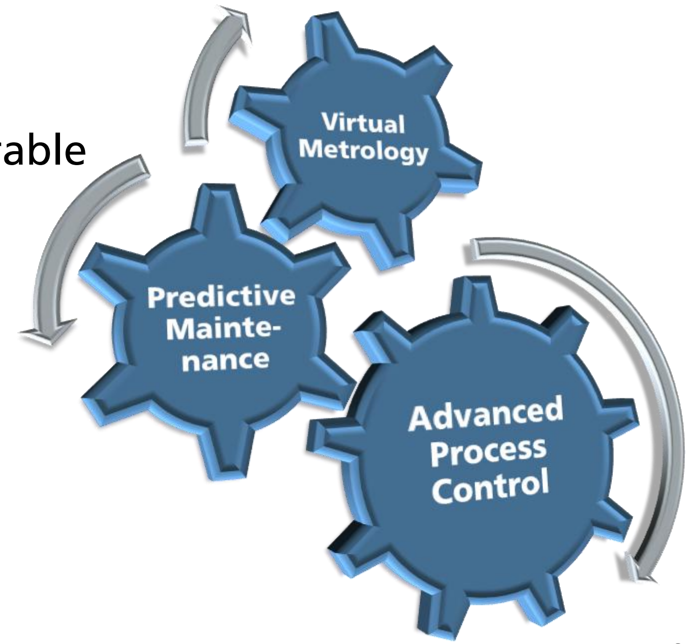
Concept of PdM for IC-manufacturing and equipment control
Overview

State-of-the-art

- Reactive Maintenance (run to fail): error-based maintenance decisions
  - Causes scrap production and unscheduled downtime
- Preventive Maintenance: time-based maintenance decisions
  - Early maintenance for security reasons leads to increased tool downtime

Deficiencies for maintenance planning

- Wear part end-of-life unknown, usually not measurable



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Concept of PdM for IC-manufacturing and equipment control

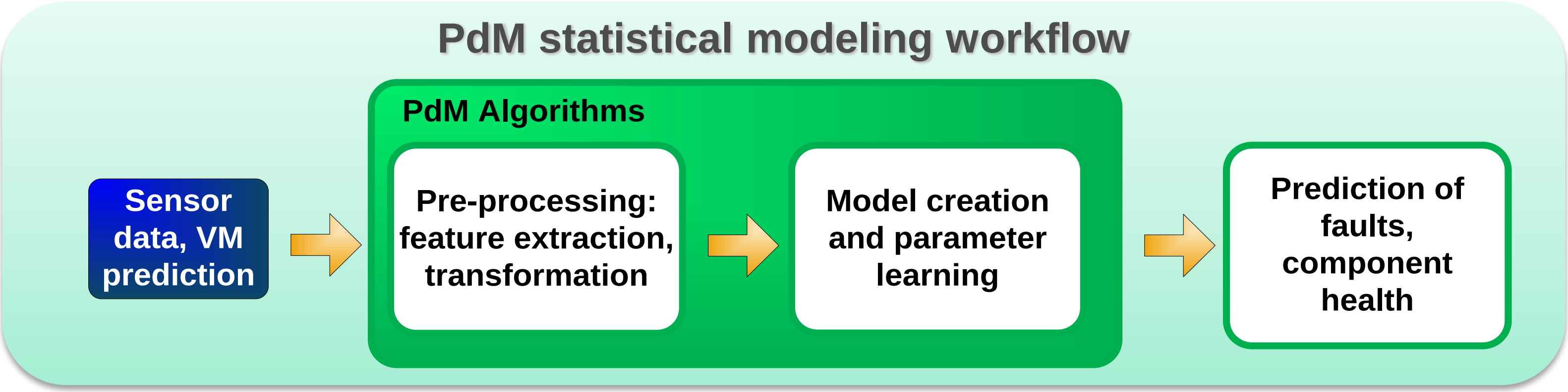
PdM objectives and benefits

PdM objectives

- Predict tool failures and wear part end-of-life from manufacturing tool data, from metrology data, and VM results

PdM benefits

- Prevention of unscheduled downtime/scrap production
- Better maintenance planning
- In-time allocation of maintenance personnel and spare parts
- Production risk assessment



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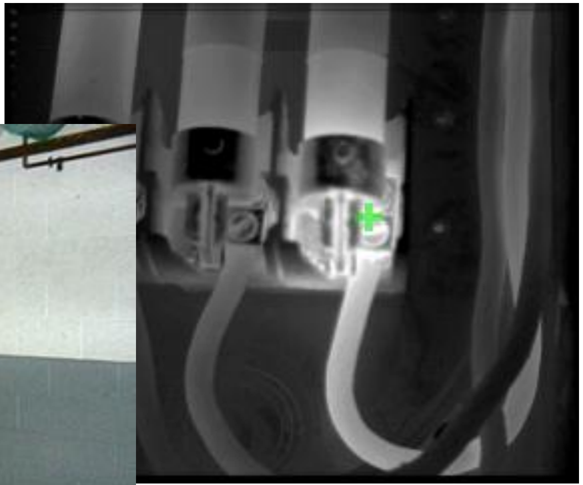
Definition of Predictive Maintenance
Other industrial branches

Different understanding of the term "Predictive Maintenance"

- Frequent manual measurements for detection of worn parts, e.g.
  - Ultrasonic micro crack detection in pipe systems
- Predictive sensors or integrated wear measurement, e.g.
  - Acoustic wave analysis of moving parts (e.g. bearings) for detection of imbalances and defective parts
  - Thermographic sensors for detection of abnormal heat in electronic components

➔ Measurement-driven approaches



Source: http://www.x20.org/library/thermal/pdm/ir_thermography.htm

http://www.irinfo.org/articles/article_11_2003_goodman.html

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Definition of Predictive Maintenance
Semiconductor manufacturing

Semiconductor industries

- "Low hanging fruits" usually already integrated into tools due to tight process specifications
- Implementation of wear measurement systems often not possible
- But: lots of data collected during processing

➔ Data-driven approaches

➔ Statistical techniques

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Definition of Predictive Maintenance
Different PdM goals and objectives

Monitoring of overall tool performance for risk assessment

- Degraded tool might cause shifts in process performance
- „Tool health factor“ for adaptive planning of control/measurement steps
- Root cause analysis for improved execution of maintenance

➔ „Global“ PdM approach

Monitoring of specific wear parts

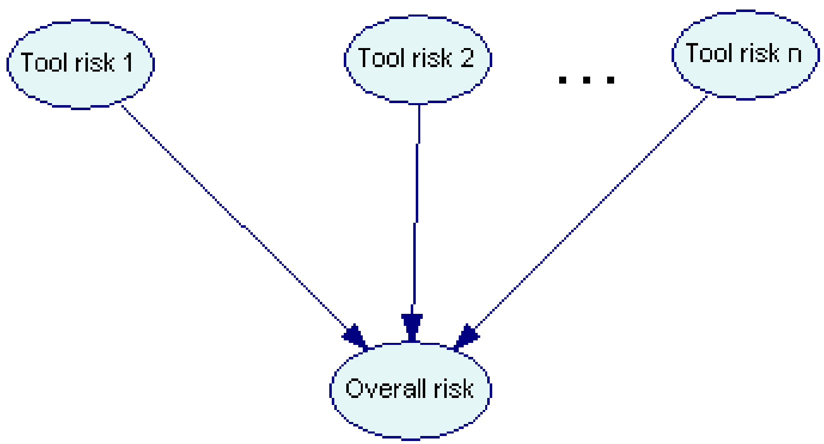
- For better planning of frequent maintenance tasks
- For better planning of spare part demand
- Better logistic planning to prevent production downtimes (bottleneck tools)

➔ „Local“ PdM approach

PdM implementation approaches
“Global” PdM approaches

Methods:

- Manual methods:
  - Knowledge management: collection of process engineer‘s experience
  - E.g. FMEA, decision support techniques
- Automated methods:
  - Representation of experience in automated decision models
  - Learning decision systems from data
  - Classification methods, e.g. Decision tree techniques, Bayesian Networks



PdM implementation approaches
"Local" PdM approaches

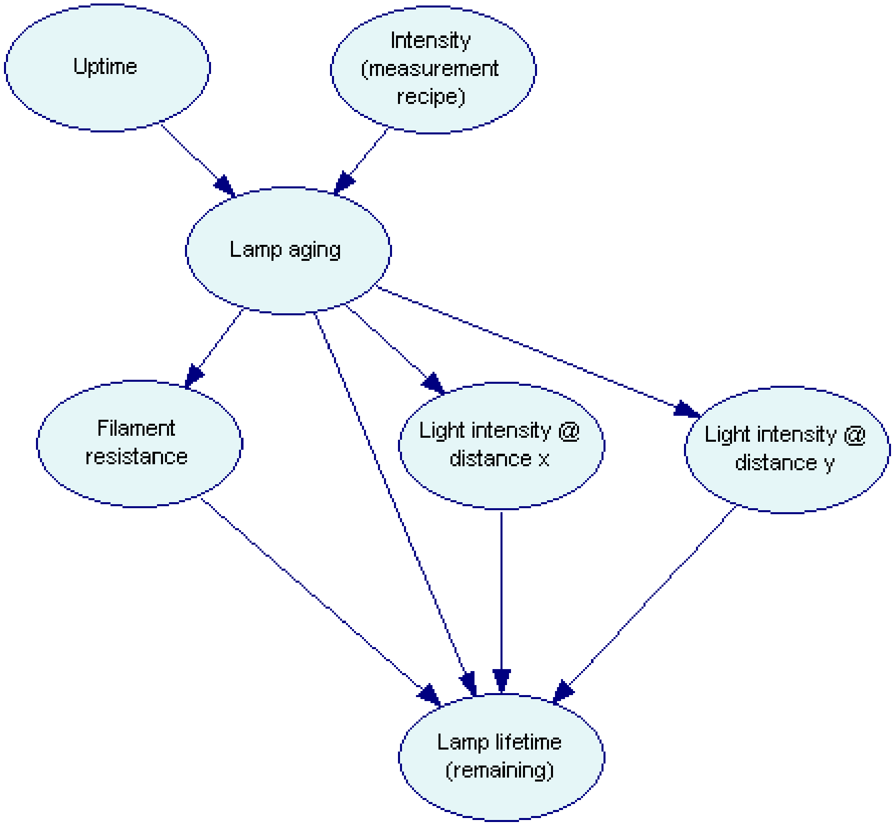
Methods:

- Measurements and sensors:
  - Often not feasible
- Physical modeling:
  - Usually complex, computationaly expensive, requires good knowledge about process and tool physics and internal control loops
  - Physical equations, Monte-Carlo methods
- Univariate statistical modeling: monitoring of single parameter as degradation indicator (similar to SPC control of products)
  - Only possible if single degradation indicator already exists
  - Time series analysis methods for improvement of degradation indicator (e.g. smoothing, extrapolation)

PdM implementation approaches
"Local" PdM approaches

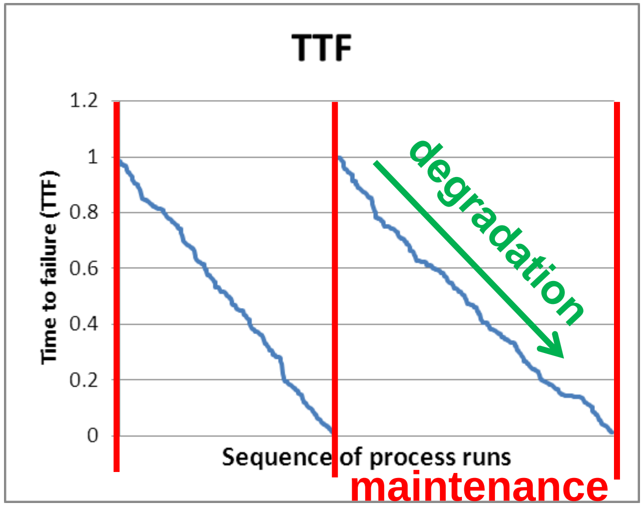
- Multivariate statistical modeling: extraction of degradation indicator from multiple tool parameters
  - Multivariate dependencies usually unknown
  - Multivariate data mining/machine learning methods, regression techniques

Prediction of lamp lifetime



PdM implementation approaches
Challenges in PdM modeling

- Noise on data resulting from:
  - High-mix production: different recipe setpoints cause frequent shifts in data
  - Intrinsic liftime of spare parts
  - Influence of maintenance on wear-part lifetime
  - Manual corrections of tool settings
  - Non-homogeneous degradation of wear parts
  - → Noise reduction techniques



- Target variable (degradation rate):
  - Has to characterize tool degradation
  - For multivariate modeling usually no target variable in learn data available (otherwise: univariate modeling possible)
  - → Offline creation of approximative degradation parameter from historical data, e.g. time to failure (TTF)

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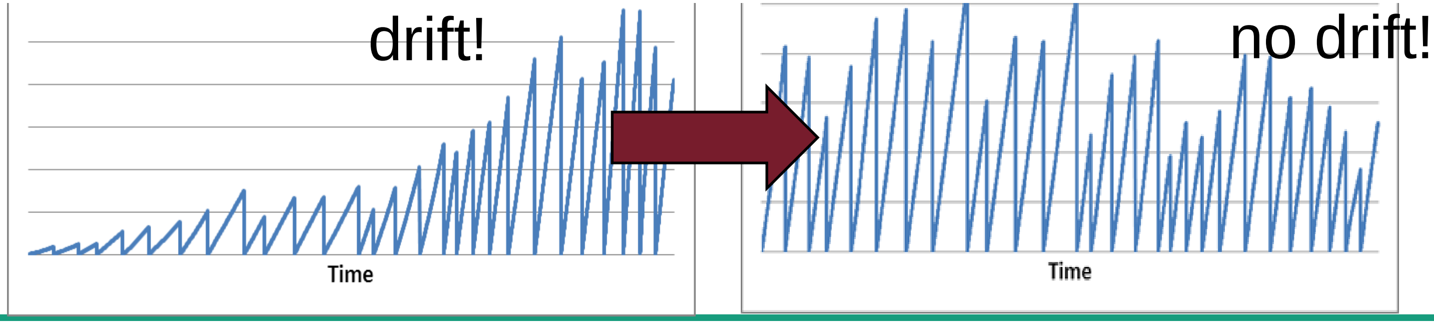
PdM implementation approaches
Challenges in PdM modeling

- Workload:
  - Future production unknown at beginning of cycle
  - → Better model performance short before wear part failure

- Drift/shift in tool behaviour:
  - Parameters might drift over several maintenance cycles
  - Maintenance may cause shift in parameters
  - Retraining of model only possible if new failures are observed
  - → „controled failures“ for creation of new learning data
  - → Compensation of drift/shift in data (e.g. methods of time series analysis)



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Prerequisites for PdM
Different kinds of data available

Tool and process data (from tool, FDC system)

- Recipe settings
- Trace data from tool
- Process data from previous processing

Measurement data (from offline measurements and quality control)

- Process results: film thickness, etch depth, CD, film composition, …
- Defectivity measurements

Logistic data (from MES system)

- Wafer motion through fab

Maintenance data (from maintenance book)

- Past maintenance actions
- Failure root causes
- Tool modifications

Prerequisites for PdM
Data requirements

Merging of data from all available sources requires:

- Identical time stamp required
- Identical number of observations required

➔ Syncronisation of data sampling

Maintenance data:

- Often only handwritten notes

➔ implementation of automated maintenance documentation procedure for storage of machine-readable maintenance data including **time, failure mode** and (if available) **information regarding used spare parts** and **maintenance procedure**

Statistical approaches to PdM
Systematic approach to PdM development

Phases in VM development as adapted from the Cross-Industry Standard Process for Data-Mining (CRISP-DM)

Equipment/process understanding
- Objective and success criteria for VM
- Analysis of equipment parameters and process steps
- Work plan

Data understanding
- Initial data collection
- Data description and exploration
- Analysis of data quality

Data preparation
- Data selection
- Data formatting
- Construction of derived variables

Modeling
- Selection of modeling technique
- Test design generation
- Model building and assessment

Evaluation
- Process and model review
- Determination of next steps (model refinement vs. move to deployment)

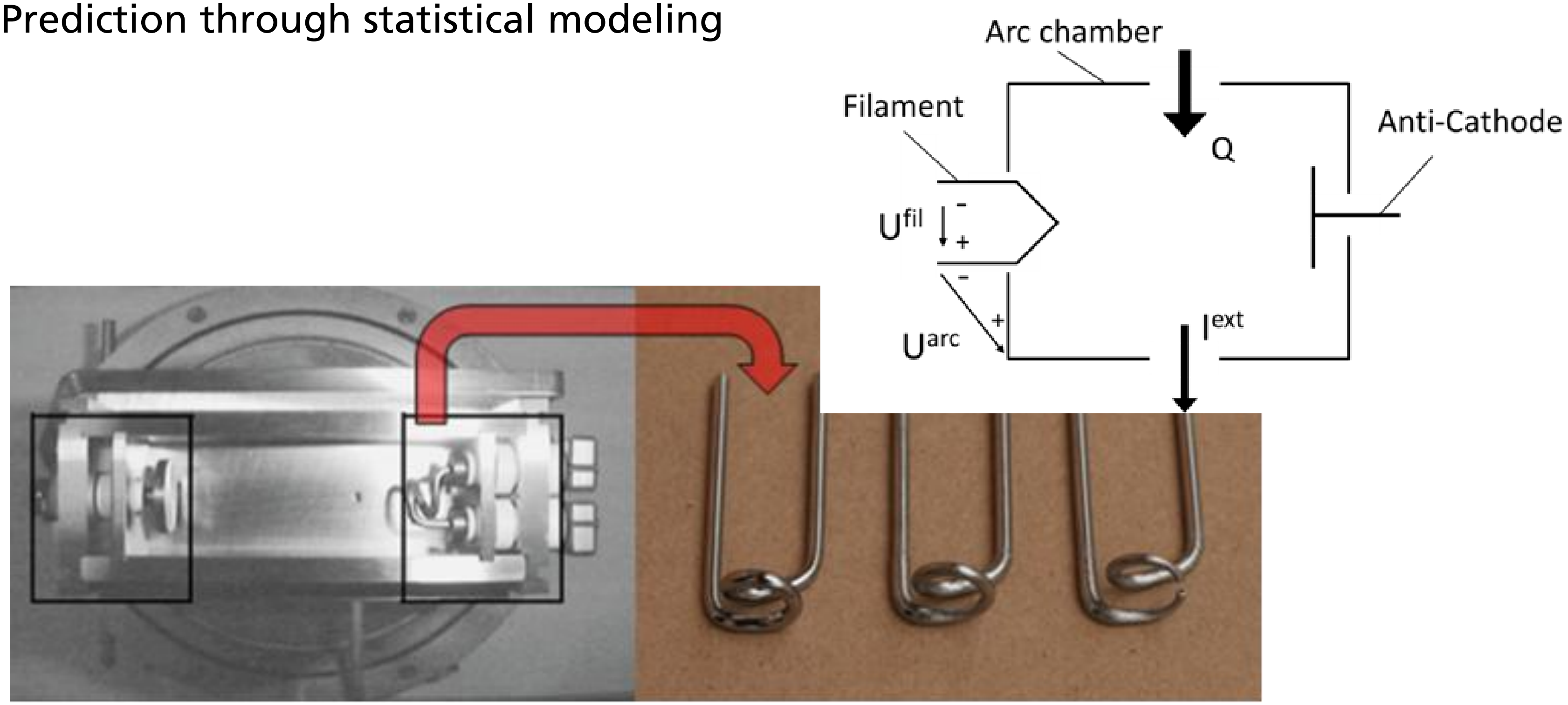
Deployment
- Planning of deployment
- Monitoring and maintenance
- Project documentation and review

PdM Example
PdM for ion implantation

Prediction of filament breakdown in ion source of implanter tool

- Ions cause sputtering of filament
- Most frequent maintenance task in ion implantation

➔ Prediction through statistical modeling



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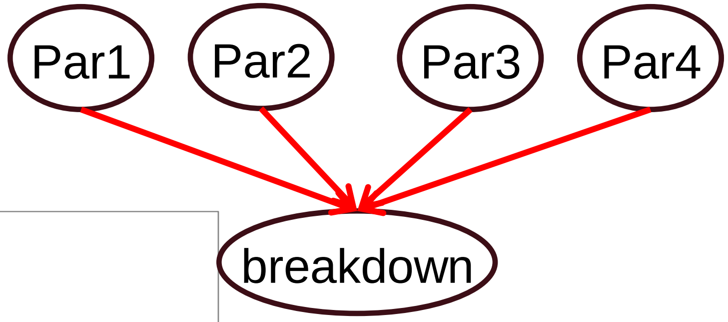
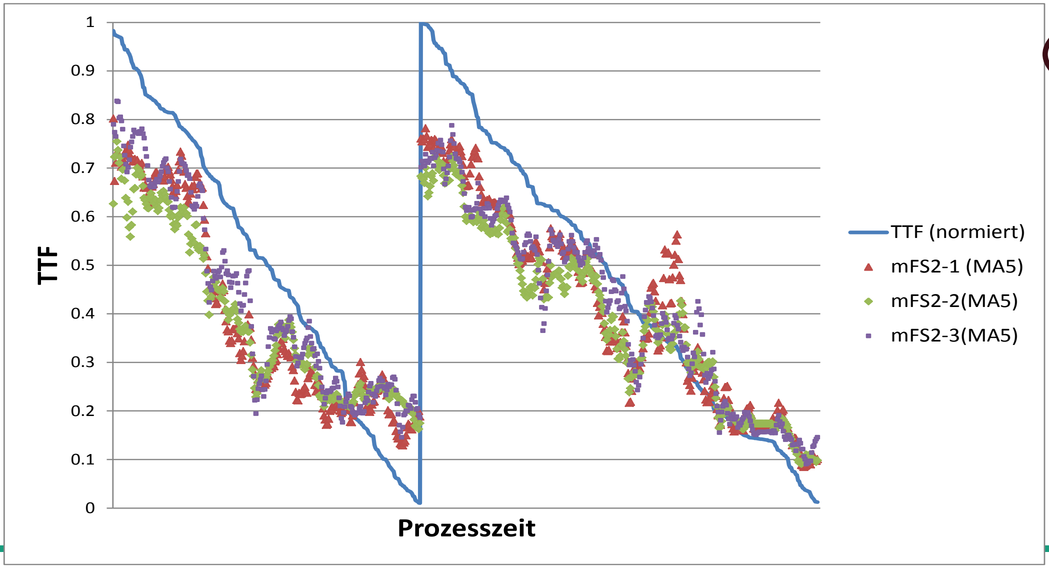
PdM Example

PdM for ion implantation

Methodology:

- Bayesian Networks with soft discretization
- Input data: tool parameters (different voltage/current values, pressure values, gas flow rates)
- Output: remaining time to breakdown
- Prediction error ~ 10h





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Conclusion

- No fixed definition of PdM
- Definition in semiconductor manufacturing: statistical modeling approach
- PdM implementation approaches:
  - "Local" vs. "Global" approach
- Challenges:
  - High-mix production
  - Availability of maintenance data
  - Existence of target variable
  - Retraining of models challenging
- Prerequisites for PdM
  - Data from different sources available
  - Collection of maintenance data