Zero Defect Manufacturing

Dimitris Kiritsis
EPFL, ICT for Sustainable Manufacturing

dimitris.kiritsis@epfl.ch
**Resistance to Failure**: An indicator of performance or condition

**Potential Failure**: the starting point to observe the potential state or condition of not meeting a desirable or intended objective, and may be viewed as the opposite of success.

**Functional Failure**: the starting point of the state or condition of not meeting a desirable or intended objective, and may be viewed as the opposite of success.

**Premature failure**
- **Premature P**: Earlier Potential Failure than intended
- **Premature F**: Earlier Functional Failure than intended

**Time (TBD)**: Residual Useful Lifetime (??)

**Degradation Phases**
- **Pre-P Period** (<P)
- **P-F Interval** (P-F)
- **Post-F Period** (>F)

Refer to [http://www.assetinsights.net/Glossary/G_P-F_Curve.html](http://www.assetinsights.net/Glossary/G_P-F_Curve.html)
Function structure model of a turbocharger
Degradation scenarios of a turbocharger

- F11 Enter exhaust gas
- F12 Rotate turbine wheel
- F13 Exit exhaust gas
- F21 Rotate shaft
- F51 Enclose turbocharger
- F42 Cool and lubricate shaft
- F43 Exit oil
- F31 Enter air
- F32 Rotate compressor wheel
- F41 Enter oil
- F33 Compress air
- F34 Exit compressed air

Degradation scenario
Function
Characteristics of the behavior of function performance degradation

\[
CoD = \frac{\sum_{i=1}^{n} (D_c - D(t_n))}{n \times D_c}, \quad \text{if } D_c < D(t_n), \text{ then } D_c - D(t_n) = 0
\]

where
- \(CoD\): (nondimensional) criticality of function performance degradation,
- \(0 \leq CoD \leq 1\)
- \(n\): number of sampling instances during the usage period
- \(t_n\): time instance when function performance measure is monitored,
- \(0\) (initial operation time) \(\leq t_n \leq\) end of life
- \(D_c\): critical level of function performance degradation
- \(D(t_n)\): function performance degradation at time instance \(t_n\)

\[
SoD = \sum_{i=1}^{n} \frac{D(t_{n+1}) - D(t_n)}{t_{n+1} - t_n}, \quad \text{if } \frac{D(t_{n+1}) - D(t_n)}{t_{n+1} - t_n} < 0, \text{ then } \frac{D(t_{n+1}) - D(t_n)}{t_{n+1} - t_n} \geq 0
\]

where
- \(SoD\): severity of function performance degradation,
- \(0 \leq SoD \leq 1\)
- \(n\): number of sampling instances during the usage period
- \(t_n\): time instance when function performance measure is monitored,
- \(0\) (initial operation time) \(\leq t_n \leq\) end of life
- \(D(t_n)\): function performance degradation at time instance \(t_n\)
- \(D_c\): critical level of function performance degradation

\[
AoD = \sum_{i=1}^{n} \frac{(D(t_{n+1}) - D(t_n))}{(D_c - D(t_{n+1}))}, \quad \text{if } D(t_n) \leq D_c, \text{ then } D(t_n) - D_c = 0
\]

where
- \(AoD\): (nondimensional) abnormality of function performance degradation,
- \(0 \leq AoD \leq 1\)
- \(n\): number of sampling instances during the usage period
- \(t_n\): time instance when function performance measure is monitored,
- \(0\) (initial operation time) \(\leq t_n \leq\) end of life
- \(D(t_n)\): function performance degradation at time instance \(t_n\)
- \(D_c\): expected function performance degradation at time instance \(t_n\)
- \(D_c\): critical level of function performance degradation
Defects are occurring and can be avoided at the Shop-floor level.

Better and more efficient production management and operation, by better resource allocation, based on product quality.

Scheduling problem
Zero Defect Manufacturing - ZDM

The objective is to eliminate as much as possible the number of defects either on parts or on manufacturing equipment by applying on one or more of the ZDM elements.

Product oriented ZDM

Machine oriented ZDM
Connections among the ZDM strategies

- **Detect**
  - Triggering factor
  - Information regarding the Defect
  - Repair
    - Part repairing actions
  - Prevent
    - Production parameters modification

- **Predict**
  - Action
  - Non defected part

**Connections**
- Detect → Predict
- Predict → Prevent
- Prevent → Non defected part
Disciplines involved in online monitoring and control of machining process conditions

- Signal processing and feature extraction
- Decision making methods (NN, fuzzy logic, etc.)
- Sensing techniques
- Statistical analysis
- Data analytics
- Root cause analysis (RCA)
- Fault diagnosis and detection (FDD)
- Design of experiments
The Z-Fact0r solution

http://www.z-fact0r.eu/

http://ict4sm.epfl.ch/
Z-DEFECT & Z-REPAIR in Intelligent Robotic Deburring cells

- **Zero defects, superior accuracy deburring**
- **Metrology aided Defects identification**
- **Z-Repair to generate an optimized deburring cycle to compensate and cancel the defects**
- **Proper compliant tools and ZD deburring strategies**
- **Integration and validation will be carried out experimentally on a prototype (TRL 5-6)**
Z- PREVENT - process planning with robot and cell accuracy

http://www.z-fact0r.eu/

Cell, tool and workpiece Calibration
Robot & tooling motion accuracy

http://www.z-fact0r.eu/
Z-DETECT - Online Defects identification

Process Monitoring and Metrology aided quality check

Fast, easy-to-process output

http://www.z-fact0r.eu/
Z-DETECT – 3D Scanning

Physical part

3D Scanning

Point cloud

Measurement plan preparation

Measurement Plan Execution

Deviation map (CAD based comparison)

CAD Model (STEP, IGES, STL)

Measurement results / Defects

Defects

http://ict4sm.epfl.ch/

http://www.z-fact0r.eu/
Parts with dimensional defects

Parts with surface defects, cracks....

http://www.z-fact0r.eu/
Production cycle – macro processes

- Powder Mixtures and preparation
- Pressing and Green Maching
- Sintering
- Final Shaping / grinding

Soft or “GREEN” State material

Hard or “DENSE” components

PRODUCTION PER ORDER – JOB SHOP ENVIRONMENT
TYPICAL PRODUCTION ORDER: 10-20 PARTS

http://www.z-fact0r.eu/
# Defect Types

<table>
<thead>
<tr>
<th>Defect Types</th>
<th>Defect 01: Geometric Tolerances</th>
<th>Defect 02: Pores</th>
<th>Defect 03: Cracks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Where They Occur</strong></td>
<td>Surface Grinding processes</td>
<td>Green Shaping Surface Grinding</td>
<td></td>
</tr>
<tr>
<td><strong>When They Occur</strong></td>
<td>Preparation of surfaces to meet required tolerances</td>
<td>1. Pressing and sintering</td>
<td>1. Sintering: Temperature gradients</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Quality of the powder mixtures</td>
<td>2. Machining: Wrong process variables</td>
</tr>
<tr>
<td><strong>Why They Occur</strong></td>
<td>Operator distraction / Wrong set of machine variables</td>
<td>Insufficient densification of the parts, Incorrect powder properties</td>
<td>Differential mechanical stress during process</td>
</tr>
<tr>
<td><strong>How They Can Be Solved</strong></td>
<td>Solution: Scrap or Reshaping</td>
<td>Solution: Re-Sintering</td>
<td>Solution: Re-Sintering</td>
</tr>
<tr>
<td></td>
<td>Prevention: tighter metrological control</td>
<td>Prevention: tighter quality checks along production cycle</td>
<td>Prevention: tighter quality checks along production cycle</td>
</tr>
</tbody>
</table>
Z-Fact0r - Big Data Analytics

http://www.z-fact0r.eu/

Machine / Deep learning

- Manage information
- Extract knowledge
- Apply intelligence

Gather
- Raw data
- Using laser-based technology

Analyze
- Context
- Extract geometrical features and variations

Identify
- Decisions
- Identify patterns / correlations

Classify
- Feedback and learning
- Feedback and learning
- Feedback and learning
- Reject VS accept VS needs rework

Portfolio of ML techniques:
- Neural Networks
- SVMs
- AdaBoost
- Random Forest
- XGBoost
- LightGBM
- Deep dense networks
- LSTM
- GRU
- Convolutional neural nets
- Autoencoders

Gather
- Feedback and learning

Analyze
- Feedback and learning

Identify
- Feedback and learning

Classify
- Feedback and learning

http://ict4sm.epfl.ch/
Statistical and Trend Analysis techniques

Data-driven technique for Anomaly Detection

Local Outlier Factor - LOF

In anomaly detection, the **Local Outlier Factor** (LOF) is an algorithm for finding anomalous data points by measuring the local deviation of a given data point with respect to its neighbors.

http://www.z-fact0r.eu/
Z-Fact0r - Big Data Analytics

Image Classification

Spectral & spatial feature extraction
- spectral features, first order texture features, Gray-level Co-occurrence Matrix and wavelet features

Sliding window approach

Feature selection
- informative and non-redundant features
- enhanced accuracy rates
- dimensionality reduction
- low computational demands

Outcomes
- ✓ automated detection
- ✓ quantitative results
- ✓ defect assessment

pixel based classification
Support Vector Machines

http://www.z-fact0r.eu/

http://ict4sm.epfl.ch/
The Meaning of Data

38.5

38.5 °C

Body temperature

Oven temperature
Characteristics of Data

- Source of data
- Measurement (sensors, assessment, observation, records, ...)
- Value
- Transformation / Interpretation
- Visualisation
- Meaning / Context
It’s about big lifecycle data transformations

Closed-Loop Lifecycle
Data-Information-Knowledge Transformations

Semantics-Model-Based Systems Engineering for Big Industrial Data Analytics

D: Data
I: Information
K: Knowledge

Manufacturers

Service Providers

IoT, CPS, ...

Products / Assets

D, I

D, I

D, I

• Mode of use,
• Conditions of retirement and disposal,
• Recovery information

Product usage info,
• Failure,
• Maintenance,
• Service event

• Product status,
• Recovery information

BOL

Design

Production

MOL

EOL

Resource

Process

Product

Resource

Process

Product

Resource

Process

Product

Resource

Process

Product

Resource

Process

Product

Resource

Process

Product

Resource

Direct Information flow

Indirect Information flow

Control flow

• Product definition data,
• Up-to-date product data

• Assembly/disassembly info.,
• Material info for reuse

• History data

linkedDesign

ZFACTOR

Zbreak

boost

BioTope

EPFL/STI/IGM/ICT for Sustainable Manufacturing
dimitris.kiritsis@epfl.ch

http://ict4sm.epfl.ch/
Bring together the Physical (Real)–Cyber (Digital)–Bio (Human/Cognitive) worlds

Adapted statement of Dr. Young-Sup Joo, I4IR plenary 13.09.2017

Capturing the Meaning of Data: Semantics & Ontologies

https://sites.google.com/view/industrialontologies/home

EPFL/STI/IGM/ICT for Sustainable Manufacturing

http://ict4sm.epfl.ch/
Ontologies & Big Data

- Scattered data in several sources, systems and services
- Different actors with multidisciplinary skills

Semantic modelling module

Knowledge Graph

Data Analytics module

- Ontology design (USM)
- Ontology rules (inference)

Semantically enriched data sets

Reports
Z-BRE4K: Predictive Maintenance

IT TRANSACTIONAL DATA

- ERP
- LOGISTICS
- QUALITY
- CRM

ET ENGINEERING

- DATA (Office Floor)

OT REAL-TIME DATA (SHOPFLOOR)

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Cognitive Functions

Coordination Functions

Reactive Functions

Integrated Quality Maintenance

Failure Mode - Effect Analysis - Criticality Analysis

Predictive Maintenance (Fusion of Data-driven and Model-based)

Learning and Collective Intelligence Engine

Online Maintainability Management

Online Condition Monitoring

Knowledge Management

AUTOWARE Engineering & Simulation Cloud Services

AUTOWARE Maintenance App Store

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https://www.z-bre4k.eu/
Advanced manufacturing processes incorporate several types of machines in the production chain like:

- **Milling machines**, producing objects by means of using rotary cutters to remove material from a workpiece of raw material

- **Coordinate-Measurement Machines (CMM)**, for measuring the physical (dimensional) geometrical characteristics of manufactured objects in order to detect defects, etc.

[http://www.boost40.eu/](http://www.boost40.eu/)
Zero defect manufacturing use case:
Smart decision workflow powered by FIWARE-IDS

Mean Time To Failure
639 days

SP25 Out of tolerance for last 10+ parts

http://www.boost40.eu/
Zero defect manufacturing use case: Smart decision workflow powered by FIWARE-IDS

http://www.boost40.eu/