Knowledge-Based Maintenance as an Enabler and Driver of Efficient and Sustainable Production Management

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Maintenance for Sustainable Production Management (1/2)
As-Is State: How OEMs and Machine Users May Gain Benefits from Data?

Reliability and durability to comply with specifications over useful life time.

Availability (Uptime) to be able to perform required functions at time $t$, $A(t)$, or over a stated period of time, $A_{st}$.

Products (Complex Industrial Systems) are used under various environmental and operational conditions in industrial value chains.

What is the link between data-driven approaches, RAM KPIs and sustainability factors?

Intelligent functions for integrative analysis and modeling along value-added chain

$\text{RAM (t)}^*$

$^*$RAM (Reliability, Availability, Maintainability)

Maintainability to be timely and efficiently retained in; or restored to a required functional state, after performing maintenance actions.

Integrative modeling and analysis

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<th>Reliability</th>
<th>Maintainability</th>
<th>Availability</th>
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KPI: Key Performance Indicator | OEM: Original Equipment Manufacturer
Maintenance for Sustainable Production Management (2/2)
How does advancing maintenance approaches facilitate achieving sustainable production management?

- Problem space (objectives of sustainable production management):
  - Environmental Conservation: Reducing emission, Optimizing energy and resource consumptions
  - Economic Enhancement: Optimizing lifecycle costing
  - Social Efficiency: Improving workforce efficiency

- Solution space:
  - Design new generation of AI-enhanced machines (Maintenance-By-Design, Self-healing, etc.)
  - Optimizing maintenance of existing machines (Maintenance-By-Operation, etc.)

Maintenance is a key for optimizing performance and efficiency of equipment and industrial machines

Only focusing on this contradicts partially with sustainability goals as physical, virtual and human resources are invested to create and operate a new machine in production facilities

Joint efforts of OEM’s and Machine Users: Extending Remaining Useful Life Time (RUL) and improving efficient operation of machines through data-driven approaches

Guiding research question: How can multiple data sources and existing prior knowledge and experiences be used for planning and optimizing maintenance (operational and tactical factors) and translating related KPIs into sustainability factors?

Knowledge-Based Maintenance (KBM)
Interpretation and Challenges of KBM at the Age of Industry 4.0

- **Knowledge-Based Maintenance** is about integrating Predictive and Prescriptive Approaches ...

  - employing AI (methodologies, methods, algorithms, tools, technologies) for analyzing, modeling, predicting and reducing the likelihood or frequency of failures and thus increasing availability in production systems, gaining benefits from multi-channel, multi-structured data sources and prior and human experiential knowledge.

- What are the challenges (scientific and practical)?
  - Proper use of multiple data sources
  - Suboptimal use of multi-structured data
  - Multi-modality of data (semantic correlation of information)
  - Multiple and overlapping reliability-centered and maintenance strategies and approaches
  - Multi-dimensionality of maintenance organization/actors/teams, processes and IT-systems

* AI: Artificial Intelligence

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Application of KBM: Integration of Dynamic Bayesian Networks (1/2)

Use-Case of a Machining Center for Drilling, Milling and Turning: Data Inputs and Decision Pipeline

Object-oriented Analysis
13 Subsystems e.g. CNC, Lubrication, Spindle sub-system (Motor, Gear box, Bearings, Belt drive, Chuck, etc.)

FMEA DB (failure modes, severity, causes, risks, maintenance actions, etc.)

Failure DBs

Maintenance Reports

Condition/Process Monitoring Data

Similarity Learning

Production DBs

Identification of failure modes of Spindle Sub-System:
- Motor: Overheating, Noise
- Belt: Worn belt
- Bearing: Deformation
- Fatigue damage
- Etc.

Dynamic Bayesian Networks (DBN)

FMEAs & Tokenized Risks

Failure Probability & Frequencies

Word (verb, noun) frequencies and associations (e.g. Noise-Motor)

Semantic Modeling, representation and graphical visualization of Failure Modes and Causes for inferential decisions (diagnostics) and prediction of failures, based on joint probability functions and past observations.

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Failure DBs

Maintenance Reports

Text Mining

Similarity Learning

Similar failure modes & problems, based on expert judgements

Case-bases

Condition/process Monitoring Data

Production DBs

Production and maintenance plans, schedules, etc.

Dynamic Bayesian Networks (DBN)

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Application of KBM: Integration of Dynamic Bayesian Networks (2/2)

Use-Case of a Machining Center for Drilling, Milling and Turning: Decision Pipeline

DBN for Monitoring and Controlling of KPIs

Monitoring Dashboard

Decision on machine health status linked to production plans

Profile of CNC Machine X (Location, Age, RUL, configuration, working conditions, historical data, etc.)

Planned vs. Unplanned maintenance

Knowledge-based approach supports informed decision-making that may impact on extending RUL and improving efficiency in operations and maintenance management.
**PriMa: Prescriptive Maintenance Model**

Reference Model for Knowledge-Based Maintenance: Generalization and Transferability

![Diagram of PriMa model](image.png)


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**Knowledge-Based Maintenance in Practice**

Knowledge Graph-based Assistance System for Troubleshooting & Documentations

![Man working on a laptop](image1.png)


[https://www.youtube.com/watch?v=QjlyE_mlWag](https://www.youtube.com/watch?v=QjlyE_mlWag)
Maintenance for Efficient and Sustainable Production Management
How does advancing maintenance approaches facilitate achieving sustainable production management?

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Overall Equipment Effectiveness (OEE)
Benchmark and Baseline KPI for Assessing Production Efficiency and Maintenance Competitiveness

- OEE is a benchmark to compare the performance of a given production asset to industry standards, to similar in-house assets, or to results for different shifts working on the same asset.
- OEE is a baseline to track progress over time in eliminating waste from a given production asset.
- It takes into account all losses, i.e. Stop Time Loss/Availability Loss, Speed Loss/Performance Loss, and Quality Loss, resulting in a measure of truly productive manufacturing time.
- Schedule Loss (shutdown, set-up) is not included in OEE
- Total Effective Equipment Performance (TEEP), adjusts OEE by considering %Utilization (scheduled loss)

OEE = Availability × Performance × Quality

How can we correlate OEE Losses to Sustainability Factors and introduce a measure for lean and sustainable production?

Translating OEE Measures to Production System Sustainability
From OEE to OSEE

- **Overall Sustainable Equipment Effectiveness (OSEE = OEE x Sustainability)** can be calculated as the relationship between the OEE and sustainability parameters (Damage/Loss Model).
- For environmental sustainability most common way is to use **CO2 equivalents** due to emissions (e.g. based on methodologies for calculating environmental impacts Ecotax, Ecovalue08, Ecoinicat-99, and Ecoinvent 3, e.g. via SimaPro Library).
- **Other emission and environmental damage sources** e.g. waste, emissions by displacement, origin of raw material, etc., correlating OEE losses and sustainability factors.
- **Economic and human factors** can be should be not be undermined (Total Productive Maintenance and Lean Management).
- This should also facilitate rating maintenance activities in terms of sustainability as **low to high competitive**.
- Integrating sustainability damage model into decision pipeline.

F. Amari & L. Koh, Aisenhanced Maintenance for Building Resilience and Viability in Supply Chains, Supply Network Dynamics and Control, Alexandre Dezul, Dmitry Iarons & BorisSkolov (Eds.), Springer, In-Press
Transfer Possibilities into Industrial Contexts
What are the major challenges and pathways for future research?

- **Success of KBM for efficient and sustainable production systems in industrial context** is strongly dependent on
  - Existence of data (e.g., failure data) and evidences (observations)
  - Correctness and validity of data (**also sustainability data, especially from process level**)
  - Correct interpretation of data (by algorithms and human)
  - Explainability of algorithm’s decision to humans
  - Modeling and incorporation of human knowledge/experiences
  - Employing simulation-based and physics-informed AI models

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As industrial engineers, on the top of this, we should examine economic and technical plausibility of KBM in each industrial application.

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Technik für Menschen.

Technology for People!

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