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# Maintenance Optimization Approaches for Condition Based Maintenance: a review and analysis

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Word cloud using an online tool Wordle® available in www.wordle.net

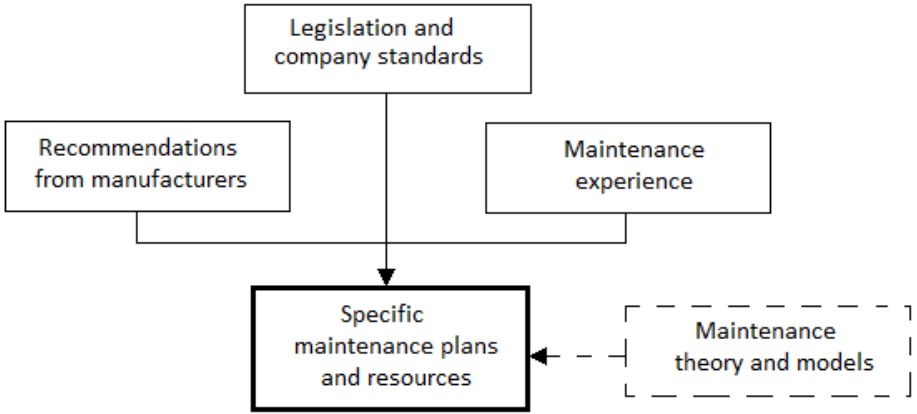
# Agenda

- Motivation and objectives
- Approach and contribution
- Problems
- Analysis
- Results
- Final Considerations and Future Work

# Motivation and Objectives

Offshore operators ought to apply maintenance optimization (MO) and find a balance between the costs and benefits of maintenance decisions (Condition-based maintenance (CBM) decisions)

- The idea: Review the literature (applications) in order to find and/or propose a concept model for a CBM system




Maintenance strategy development (Rausand & Høyland, 2004)

# Approach and Contribution



Identifying the main attributes of MO approaches, the main actors and their roles, the problems frequently reported, etc.

In this qualitative research, a set of applications was analyzed under a SE approach resulting in two theoretical constructs

- ✓ A concept map and a set of Guidelines for a CBM program implementation plan

# A Previous Conducted Survey



| Year | Publications [n.] |
|---|---|
| -1969 | 1 |
| 1970 – 1974 | 4 |
| 1975 – 1979 | 17 |
| 1980 – 1984 | 20 |
| 1985 – 1989 | 45 |
| 1990 - | 25 |
| Total | 112 |

Source: (Dekker, 1996)

| Category | Publications |
|---|---|
| Proposed model | 48* |
| Case study | 42 |
| Application tool | 14 |
| Discussion paper | 8 |

* 22 applied to real data and 26 with no further details on model application. Based on (Dekker, 1996:232).

Search words: **“maintenance”, “replacement”, “repair”, “optimization”, “application(s) and “case study(ies)”**

as inputs on the INSPEC database

# Recent Cases
## (from different industry sectors)

Filtered according to the theory under construction

| Methods and/or techniques | Cases | Freq. |
|---|---|---|
| Empirical modeling | (3), (4), (5) and (6) | 4 |
| Markov decision methods | (3) and (4) | 2 |
| Simulation | (7) and (9) | 2 |
| Gamma process | (1) and (7) | 2 |
| Weibull distribution | (2) | 1 |
| Wiener process | (5) | 1 |
| Total | | 12 |

4 - Case-studies
4 - Proposed models
2 - Application tool
2 - Discussion papers

Applications 3, 4, 7 and 9 are Markov related approaches
Application 7 is a combined approach

# Problems and Concerns
## (reported by key-informants)



*"… concern data collection and analysis. Application of models requires a good formulation of the problem, which is not easy since most concepts used (such as failure), allows various interpretations.*

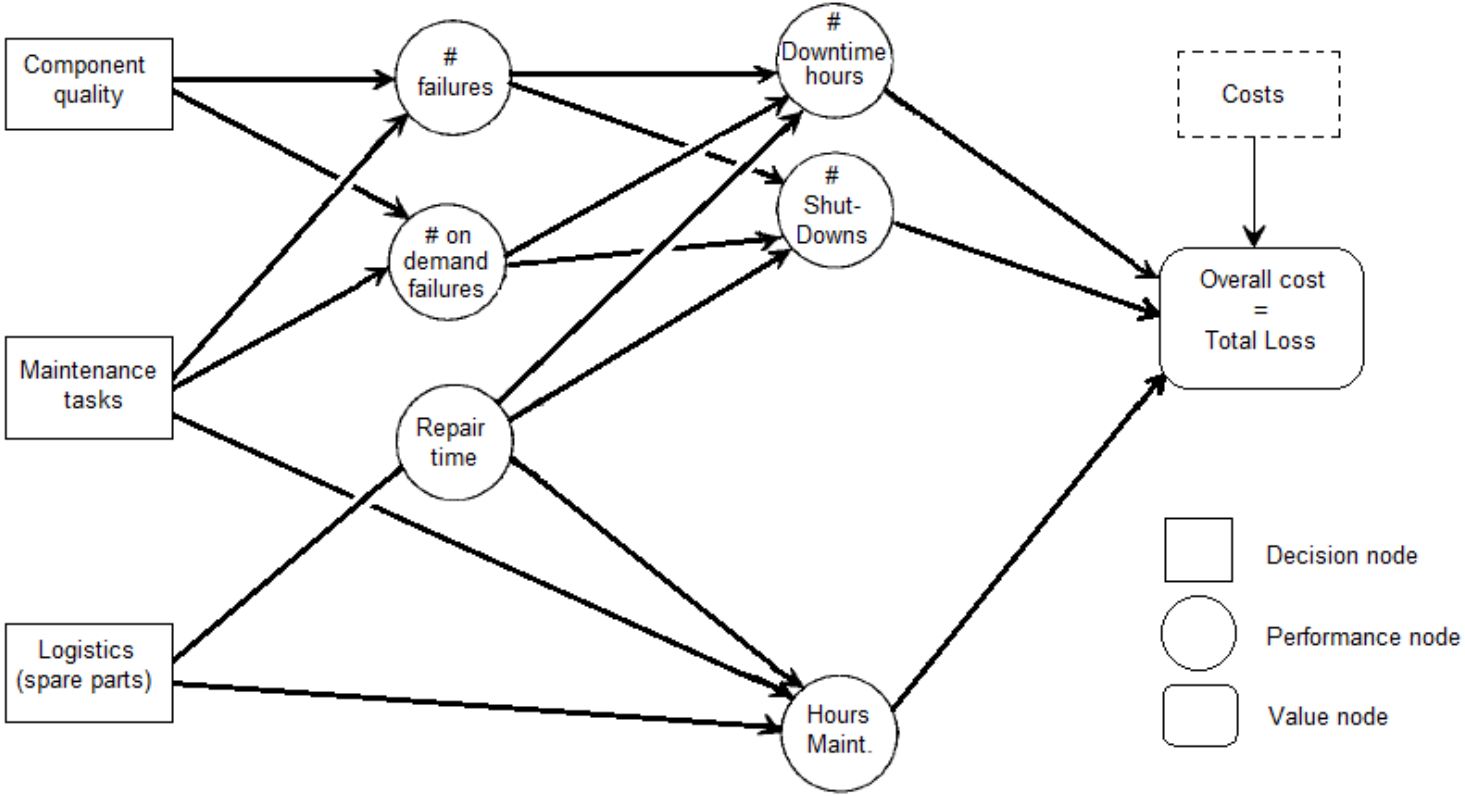
*Furthermore, many models are not robust against violations of assumptions or misinterpretation of their concepts."*

Dekker (1996)

*"… in spite of the great number of methods, mathematical models for maintenance optimization are hardly used in practice. One reason can be that there are often difficulties in providing the proper amount of data."*

Welte, Vatn and Heggset (2006)

# Models




Influence diagram for a maintenance optimization model (Vatn, Hokstad and Bodsberg, 1996)

# Findings from key-informants

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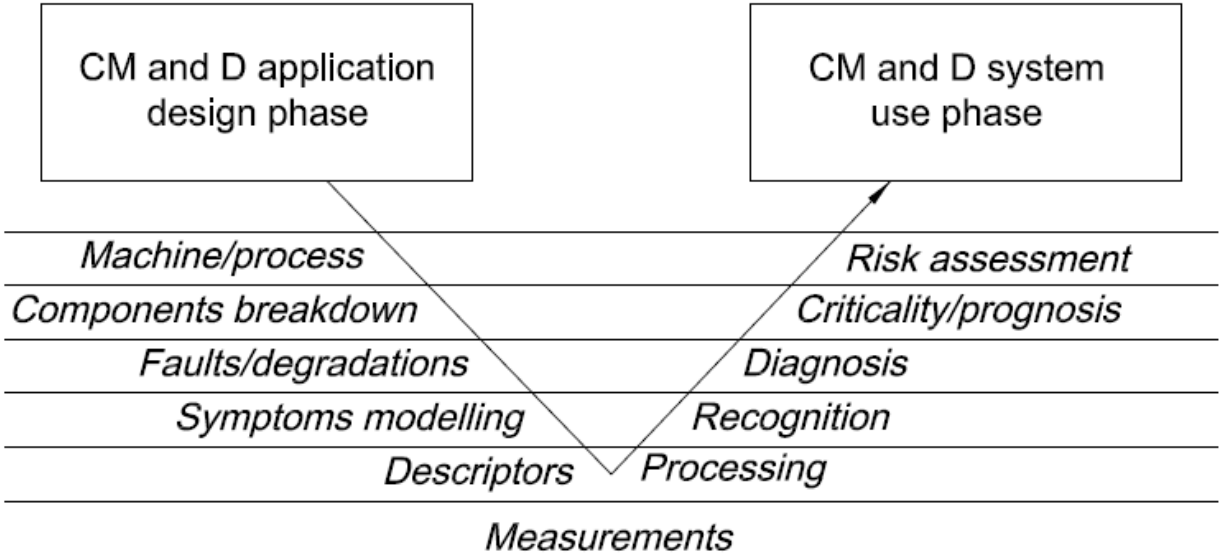
*"… the need for such diverse expertise may be one of the reasons why it has been so hard to implement model based maintenance approaches (…)*

*… decision theory, data analysis and expert judgement methods are essential to establish credible input data (…) and a thorough operational experience is required to establish optimal methods".*

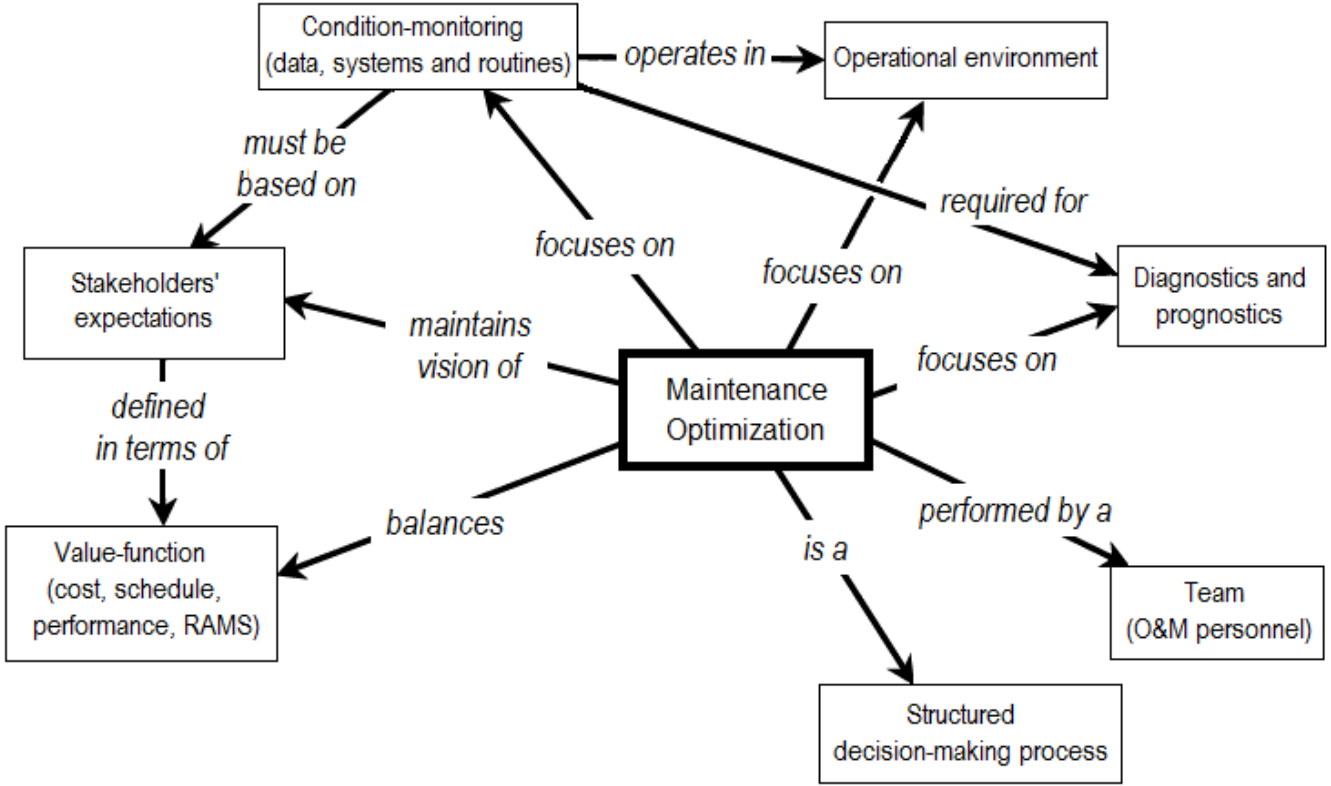
Vatn, Hokstad and Bodsberg (1996)

# Guidance from Standards




Condition monitoring and diagnostics (CM&D). Source: ISO 13379:2003

# Results
## (a concept map)




Concept map for CBM ontology, inspired by (Bahill et al, 2002)

# Results
## (guidelines for an implementation plan)



### Step 1 - Formulation of the problem
Information about the system and the actions open to management
System functions, importance and boundaries
Goals and scope of analysis
Agreed terminology
System's states space/criteria

### Step 2 - Construction of a model of the system
System degradation in time and possible consequences for the system
System functions and the respective failure characteristics
Databases, data collection and criticality analysis
Condition monitoring routines and degradation mechanisms

### Step 3 - Calculation of solution through the model
An objective-function and optimization technique
Diagnostics and prognostics analysis
Experiments

### Step 4 - Testing of the model/solutions
Evaluation of the model parameters and results
Tuning up the models

### Step 5 - Establishment of controls of the solution;
Assess the system's condition

### Step 6 - Implementation and follow-up
Decision-making (communication and reasoning)
Maintenance action (planning, scheduling and execution)
Feedback.

# Final Considerations
## (requirements for the maintenance organization)

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- Managing communication, coordination and collaboration among specialists
- Establish:
  - A structured decision-making process (with a proper analytical capacity)
  - Expert's judgment methods and a strong notification culture (routines for machine event's recording) and
  - Machine monitoring and feedback routines (put forth on analysis)
- Improve, if necessary, the related work-processes

# Summary and Future Work

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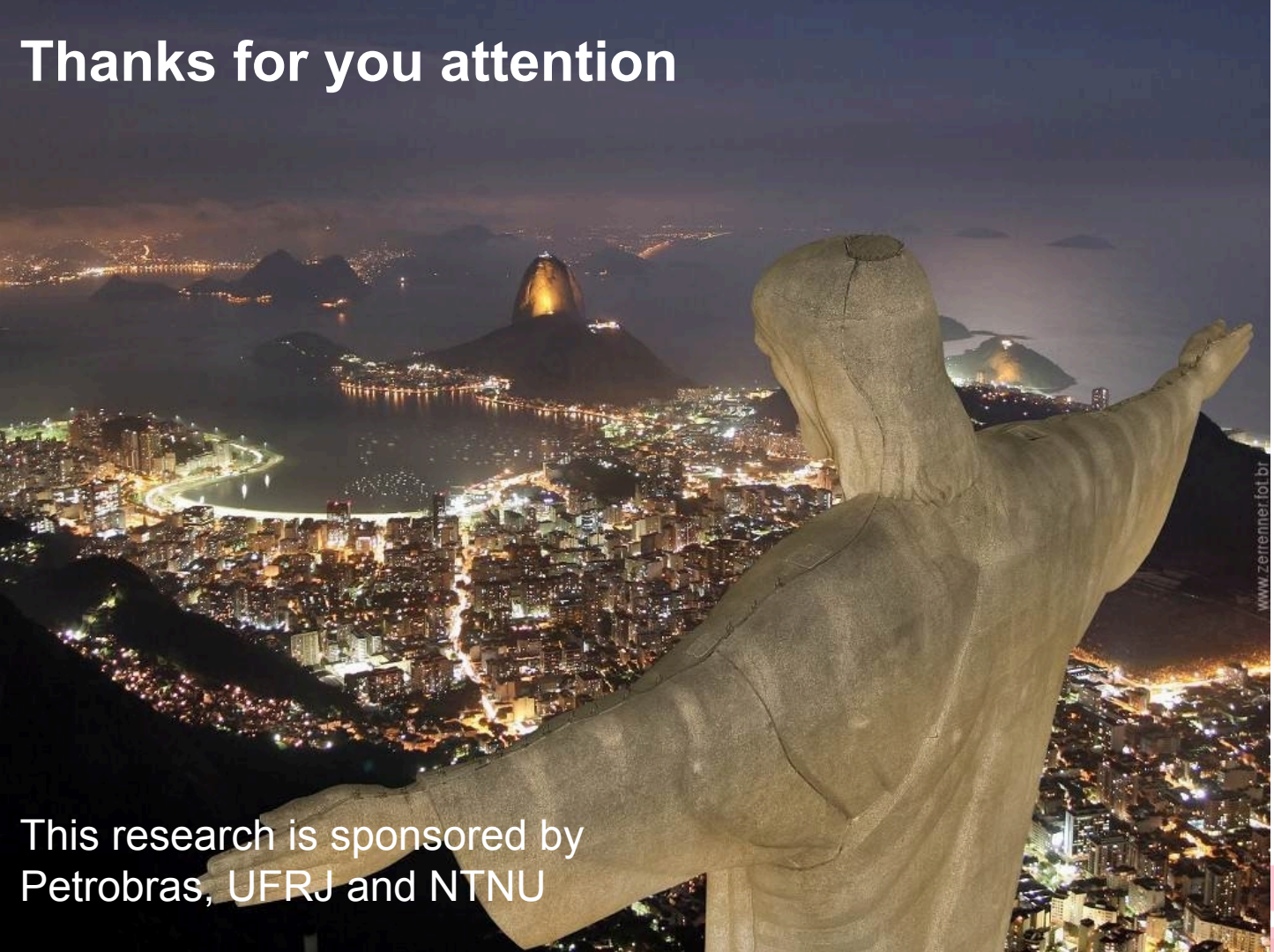
**In summary**

- ✓ System availability is one of the most important headings leading to the best maintenance and renewal strategy
- ✓ Actions should address the most relevant degradation mechanisms and
- ✓ System condition should form the basis for O&M decision

**As future work (for the related PhD)**

- ➢ Apply Markov methods for CBM
- ➢ Develop a Simulation model and perform experiments in order to identify relevant aspects for decision-making and
- ➢ Interview practitioners and experts (in Norway and in Brazil) in order to develop a condition-monitoring network for the Brazilian offshore operational environment.

# Thanks for you attention

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# (Appendix) Table 3 – Applications of maintenance optimization

| N.- Publication category / Characteristics | 1-CS | 2-AT | 3-PM | 4-PM | 5-PM | 6-CS | 7-CS | 8-AT | 9-CS | 10-DP | 11-DP | 12-PM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Author / Year | Saarela et al, 2014 | Hidalgo & Souza, 2014 | May and Mcmillan, 2014 | Jirsak et al, 2014 | Etienne et al, 2014 | Machado et al, 2014. | Welte, Vatn and Heggset, 2006. | Medina-Oliva et al, 2014 | Lundtofte and Solibakke, 2014 | Dekker, 1996 | Heng et al, 2009 | Vatn, Hokstad and Bodsberg, 1996 |
| Industry-sector / application level (unit or system) / equipment type | Nuclear power generation / unit / Air Filters | Hydro power generation / unit / Speed regulators of Hidro generators | Wind power generation / system / Offshore Wind turbines | Water utility / unit / Rapid Gravity Filter | Space / system / Satellite | Oil & Gas / system / Power generation (Gas turbine engines of a FPSO) | Hydro power generation / system / Hydro power components | Maritime transportation / system / Fuel engines | Oil & Gas / system / (FPSO - Power generation; Recompression and; Water injection) | All / NA / NA | All / NA / NA | Processing plant (generic) / unit / components of a processing plant |
| Maint. Optimization problem / Approach type (problem statement) / Obs. | Predictive maint. / RUL Modeling | Predictive maint. / Reliability / multicriteria | Scheduled maint. - Probabilistic | Scheduled maint. Probabilistic / Hidden Markov model | Scheduled maint. PHM - Prognosis and Health Monitoring | Predictive maint. / RUL Modeling (Empirical TTF modeling for gas metering valve related faults) | Scheduled maint. Optimization / Probabilistic (Markov chain model / Gamma distribution) | Predictive maint. / PHM - Prognosis and Health Monitoring - application in KASEM e-maintenance | RAM analysis model using MCS and Markov method | Discussion paper | Discussion paper | Scheduled maint, optimization / Multi-objective linear optimization model |
| Objective/value-function / Method(s) | TTF estimations | PM intervals by using decision's preference (min cost or maximiza reliability/ PROMETHEE | Min. Costs of CBM under system detection rates and False alarms | Condition-monitoring / Markov process | Health monitoring and prognostics | Data driven TTF estimations | Condition-monitoring / Markov | Minimize the effects of unexpected system failures / predictive diagnostics | RAM analysis and comparison between MCS and Markov method. | Survey / Search on the ISPEC database | Survey | Min. Cost by optimal maint. schedule for components of a system according to performance measures. |
| Decision figures (criteria) / Performance variables | Dif. Pressure etc. | Reliability and costs | Costs, detection rates, false alarms | Performance Data | Cond. Monitoring data | Exhaust temperature spread | Cond. Monit. data, costs and discount rate | Cond. Monit. data | Time to failure | NA | NA | RAMS and costs |
| Model used (Stochastic process) / Constrains taken | Gamma process | PROMETEE method / Exponential | Hiden Markov Model/Chain | Hiden Markov Model | Wiener process | Regression-based model | Markov chain model / Gamma distribution and MCS | Software KASEN e-maintenance | Markov method and MCS | Survey | Survey | Weibull law |