A modelling methodology for the assessment of preventive maintenance on a compressor drive system

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Introduction to the problem

Huge rotary machines are...

- used for separation, compression and boosting
- required to have high reliability

As of today, high cost comes with

- robust-by-design machines
- rigorous preventive maintenance

Therefore,

- move from age- or calendar-based to condition-based maintenance
- assess its benefits and risks

Figure: First compressor train for the Åsgard field (Statoil)

Framework of a typical Compressor Drive System (CDS)

- Multi-unit system
- Degradation and failure
- Condition monitoring
  - Some are continuously monitored
  - Some are periodically inspected
- Maintenance policy
  - Most are under calendar-based maintenance
  - Some are under short-term proactive maintenance
- Seasonal operation profile
  - Full capacity required in peak usage season
  - Reduced capacity in other periods

Problem statement

Questions...

- Will the system survive in the coming peak season without loss of production?
- How much to gain or lose by changing inspection interval of some components?
- Whether to trigger PM out of peak season as we see current system condition?
- What to replace during maintenance?
- Is it possible to remove unnecessary regular maintenance interventions?

and so on...

System description

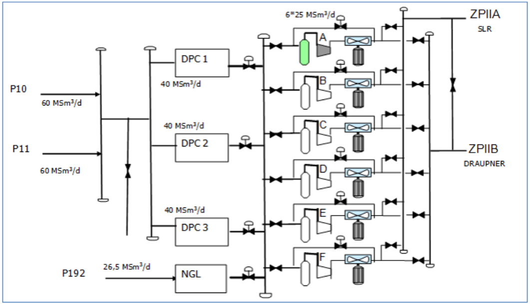


Figure: A diagram of six compressor drive trains

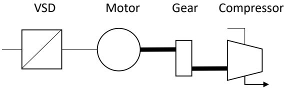


Figure: A diagram of one compressor train

VSD and Gear

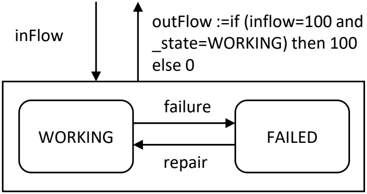


Figure: Automaton for VSD and Gear

Compressor

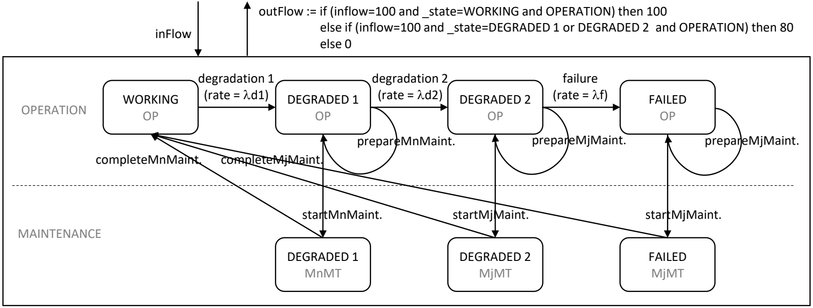


Figure: Automaton for Compressor.

Motor

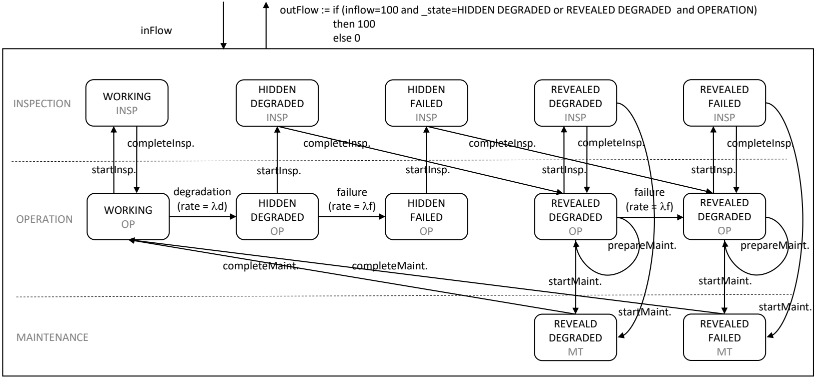


Figure: Automaton for Motor

System description

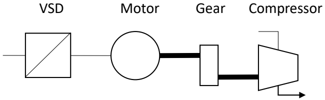


Figure: One CDS train

- discrete states with degradation
- perfect monitoring and inspection
- delayed maintenance, time to repair

Modelling methodology

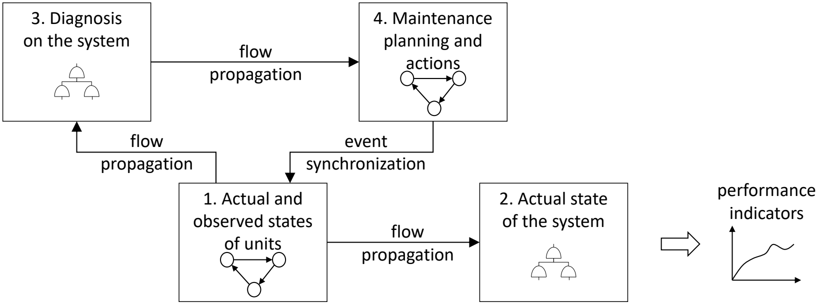


Figure: Architecture of the model

Modelling language AltaRica 3.0

The modelling language can handle modelling challenges like:

- degradation process, monitoring policies, maintenance rules
- very large state spaces
- information propagation through network of components
- calculation of performance indicators
- reuse of basic patterns

step 1. State-based model for each unit type

Local behaviours

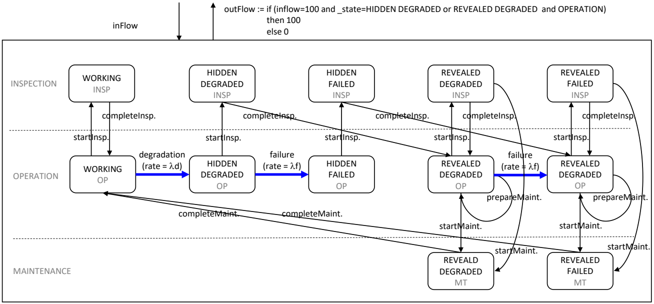


Figure: Automaton for Motor.

step 1. State-based model for each unit type

Global commands

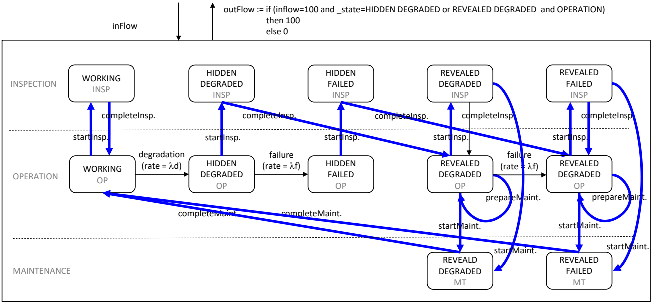


Figure: Automaton for Motor.

step 1. State-based model for each unit type

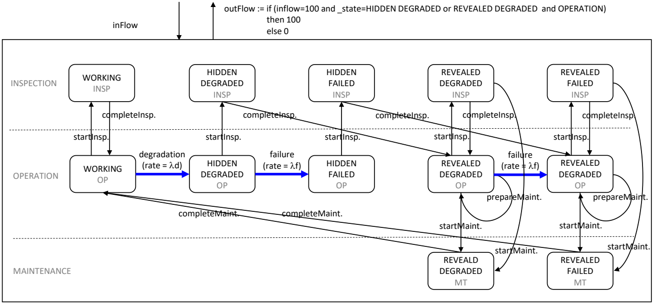
Domains and variables

```
domain State{W, HD, RD, HF, RF}
domain Phase {OP, MAINT, INSP}
domain Season {WINTER, SUMMER}
domain Clock {STB, CALL, READY}
class MOTOR
    State _state (init = WORKING);
    Phase _phase (init = OPERATION);
    Season _season (reset = WINTER);
    Clock _clock (init = STB);
```

Figure: The AltaRica code implementing domains and variables.

step 1. State-based model for each unit type

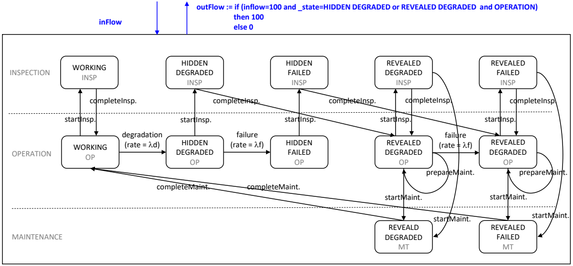
Events and transitions




```
transition
    degradation: _state==W and _phase==OP -> _state := HD;
    failure: _state==HD and _phase==OP -> _state := HF;
    failure: _state==RD and _phase==OP -> _state := RF;
```

step 1. State-based model for each unit type

Assertion




```
assertion
    outflow := if inflow==100 and ((_state==W or _state==HD or _state==RD) and
                _phase==OP) then 100 else 0;
```

step 2. Instance and composition of basic construct

One train

```
class Train
    RepairableUnit VSD;
    RepairableUnit Gear;
    COMPRESSOR Compressor;
    MOTOR Motor;
    Real inflow (reset = 100);
    Real outflow (reset = 100);
    assertion
        VSD.inflow := inflow;
        Motor.inflow := VSD.outflow;
        Gear.inflow := Motor.outflow;
        Compressor.inflow :=Gear.outflow;
        outflow := Compressor.outflow;
    ...
end
```

Figure: AltaRica code implementing one train

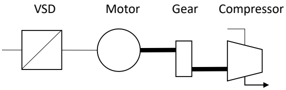


Figure: A diagram of one compressor train

step 3. Performance indicators

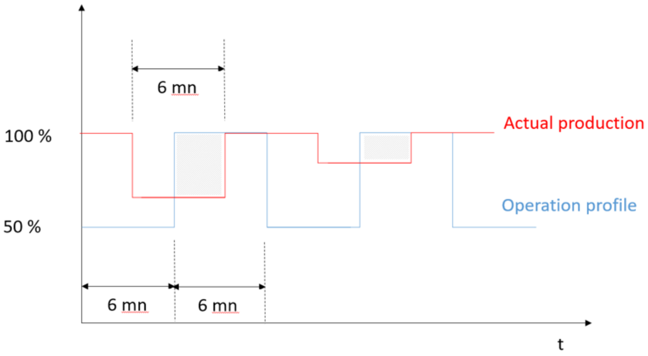


Figure: A diagram with operational and maintenance profiles

step 3. Performance indicators

```
block Plant
    ...
    Real capacity (reset = 100);
    observer Real Production = production;
    observer Real ProductionLoss = C.demand - production;
    assertion
        ...
        capacity := (T1.outflow + T2.outflow + T3.outflow + T4.outflow +
                    T5.outflow + T6.outflow)/6.0;
        production := if C.demand<capacity then C.demand else capacity;
end
```

Figure: The AltaRica code implementing performance indicators

step 4. Model checking

Tools embedded in AltaRicaWizard:

- stepwise simulator
- stochastic simulator

We need to assign in the simulator:

- mission time
- number of simulations
- step etc.

Input parameters

Component	VSD	Motor	Gear	Compressor
λ_{d1}		$1.0e-6$		$1.0e-6$
λ_{d2}				$1.0e-5$
λ_f	$1.0e-7$	$1.0e-5$	$1.0e-7$	$1.5e-4$
ρ_{mn}		4380		2190
ρ_{mj}				4380
δ_{mn}	6	365	6	182.5
δ_{mj}				365
τ		730		
Δ		12		

Maintenance optimization scenarios

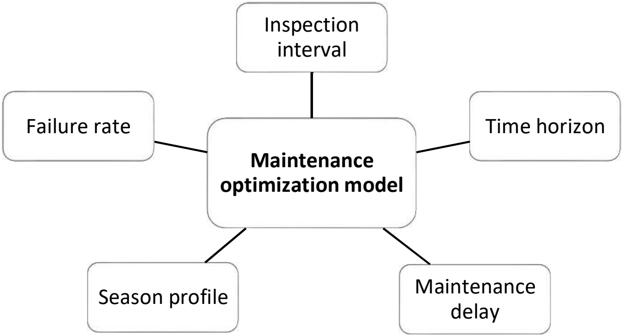
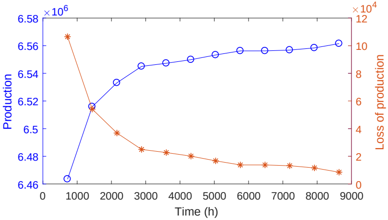
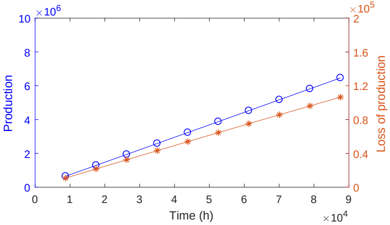


Figure: A map of maintenance optimisation scenarios

Numerical result



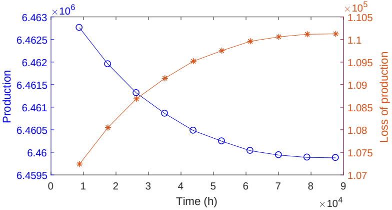
(a) inspection interval



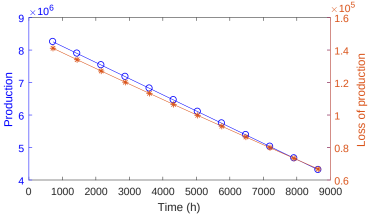
(b) Mission Time

Figure: Production and loss versus inspection interval and mission time.

Numerical result



(a) Maintenance delay



(b) Season profile

Figure: Production and loss versus maintenance delay and low demand duration.

Summary

- A preventive maintenance model on a compressor drive system
- Formal modelling formalism AltaRica 3.0
- Multi-unit systems model with constraints
- Health indicators like production and production loss
- Inspection and maintenance assessment and optimisation

Further work

1. degradation profile (exponential, Weibull, empirical distribution)
2. season profile (fluctuations in demand)
3. monitoring policy (inspection effectiveness, scheduling at system level)
4. maintenance policy (intervention priority, system level planning)

Thank you for your attention!

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