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Performance Assessment of Redundancy Strategies for Systems Subject to Random Shocks

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Outline

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- Case study
- Modelling Approach
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- Summary
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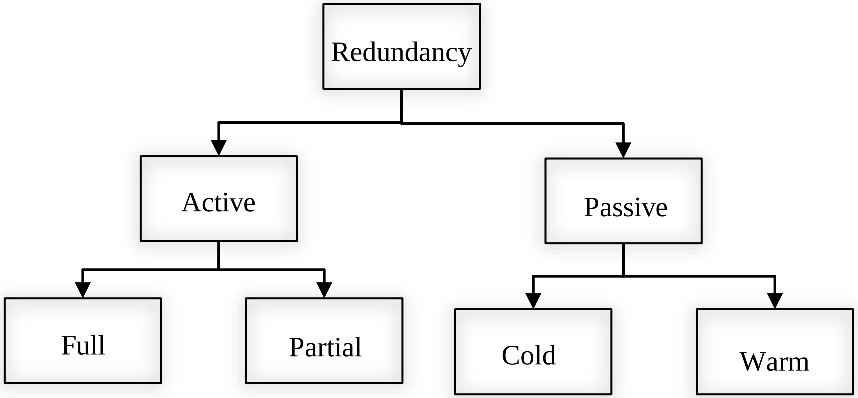
Introduction

- Redundancy means the use of two or more items or components to fulfil a specific performance or functional requirement of a system.
- Essential for achieving high system reliability and availability.
- Additional benefit is load sharing between active components.
- Broadly classified into:
  - Active
  - Passive



Introduction

- Traditional assessment assumes independence.
- Most works that consider dependence mainly focus on failures due to workload.
- In some cases, the system are also subject to random shocks that affect the performance.

Objective

- Assess the performance of two redundancy strategies for a system that is subject to degradation due to workload and random shocks.

Case Study – Subsea Multiphase Pumps [1]

- We consider a subsea multiphase pump (MPP) system with 3 pumps installed.
- The system is used to increase the production from subsea oil and gas wells.
- Based on the forecasted production profile, two pumps are sufficient to meet the required capacity from the system.

Fig. Typical subsea field layout with wells connected to a central manifold, a pump station (in red) and a topside facility
Source: Ekerberg et. al.(2022)[1]

Degradation Mechanism

- Erosion and abrasion due to sand production.
- Sand screens are installed at the wellbore to mitigate wear effects on pumps.
- Continuous sand production erodes the sand screen leading to failure of the sand screen and resulting accidental sand event (shock).
- The sand event has a detrimental impact on the pump performance.

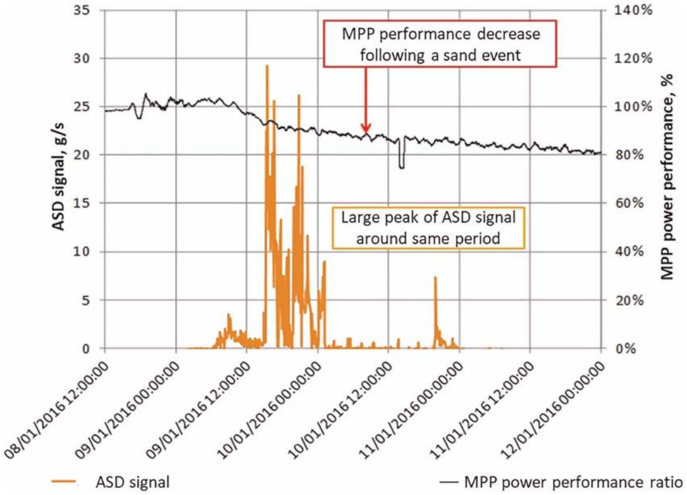


Fig. A transient sand event effect on the MPP performance.
Source: Ekerberg et. al.(2022)[1]

Assumptions

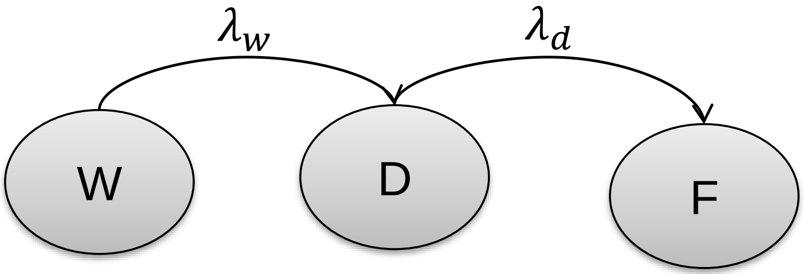
- We assume that each pump can contribute 60% towards the required production from the system but depends on the state of the pump.
- Each active pump can be in 3 discrete states:
  - Working (W) – 60%
  - Degraded (D) – 45%
  - Failed (F) – 0%
- Total output from the system depends on number and state of active pumps.
- Random sand events affects all active pumps. The state of the pump is worse after the event.

Assumptions

- In the active redundancy set-up, all 3 pumps are running from the start and share the load.
- In the passive redundancy, 2 pumps share the load from the start while one pump is on standby.
- Standby pump is activated only when required, total output < 100%.
- There is a fixed probability, of not being able to activate the standby unit on demand.

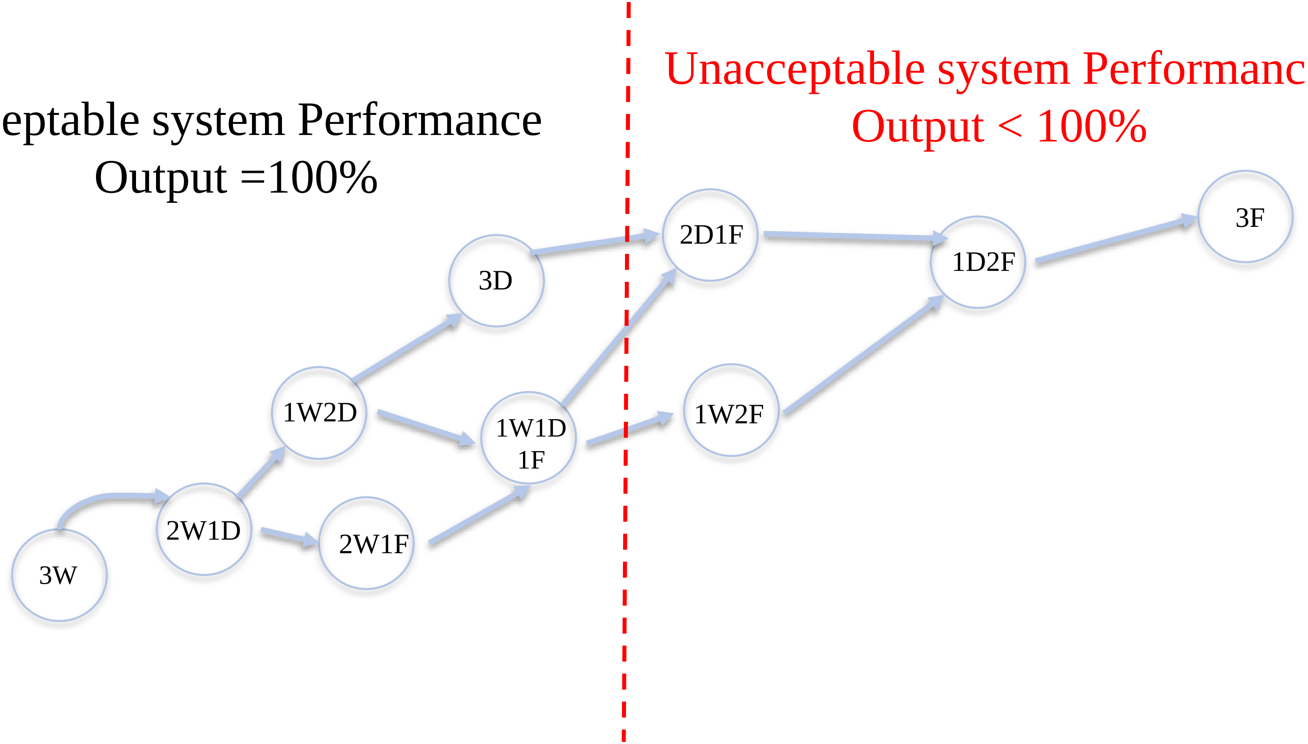
Modelling Framework

- We assume that transition between discrete states of the pump follows a Markov process with constant transition rates.
  - λ_w between W and D
  - λ_d between D and F
- The occurrence of random sand events has a constant rate of arrival, λ_s.
- Repair is done on system level and carried out when the total output is below 100.
- There is a deterministic delay before repair.
- Repair is assumed to put the system back in as good as new state.



State transition

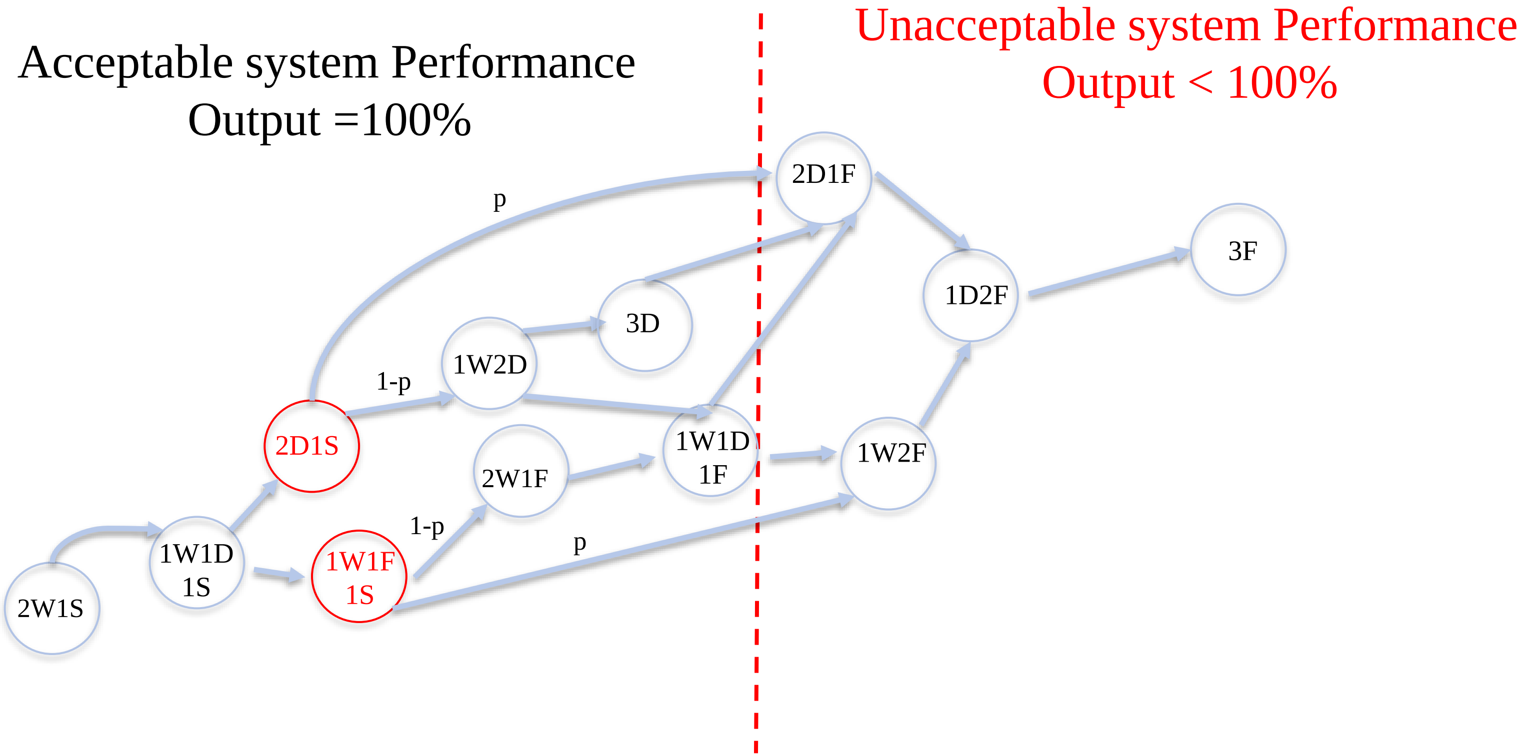
Possible transitions (Active)



Acceptable system Performance
Output =100%

Unacceptable system Performance
Output < 100%

Possible transitions (Passive)



Dependence modelling

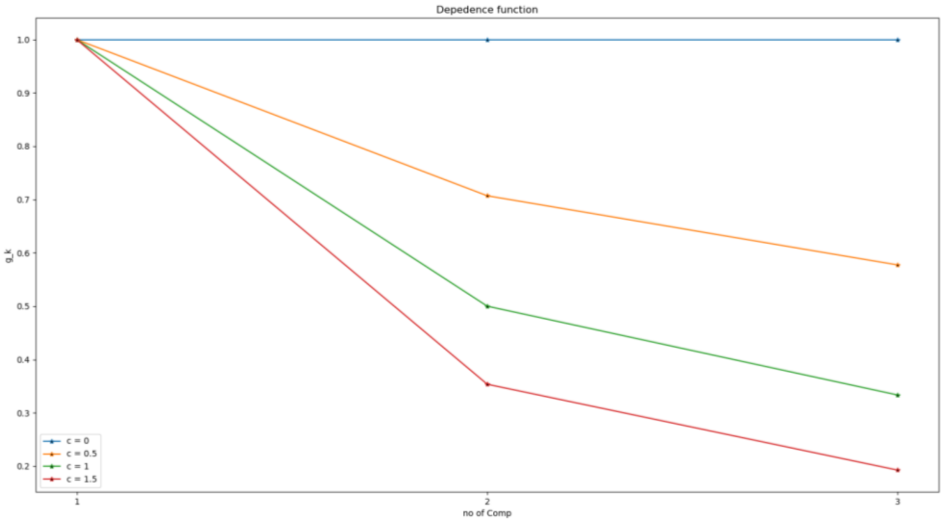
- To incorporate load sharing into our system model, we apply a dependence function.
- Failure rate with k functioning components is given as:

$$\lambda_0 . g(k)$$

- Where g(k) is the dependence function defined as:

$$g(k) = (\frac{1}{k})^c$$

- c is the load sharing factor. Higher values of c means that redundant components benefits more from load sharing.
- Some special cases:
  - c = 0. No load sharing
  - 0 < c < 1. Weak load sharing
  - c = 1. Proportional load sharing
  - c > 1. Strong load sharing



Performance Assessment

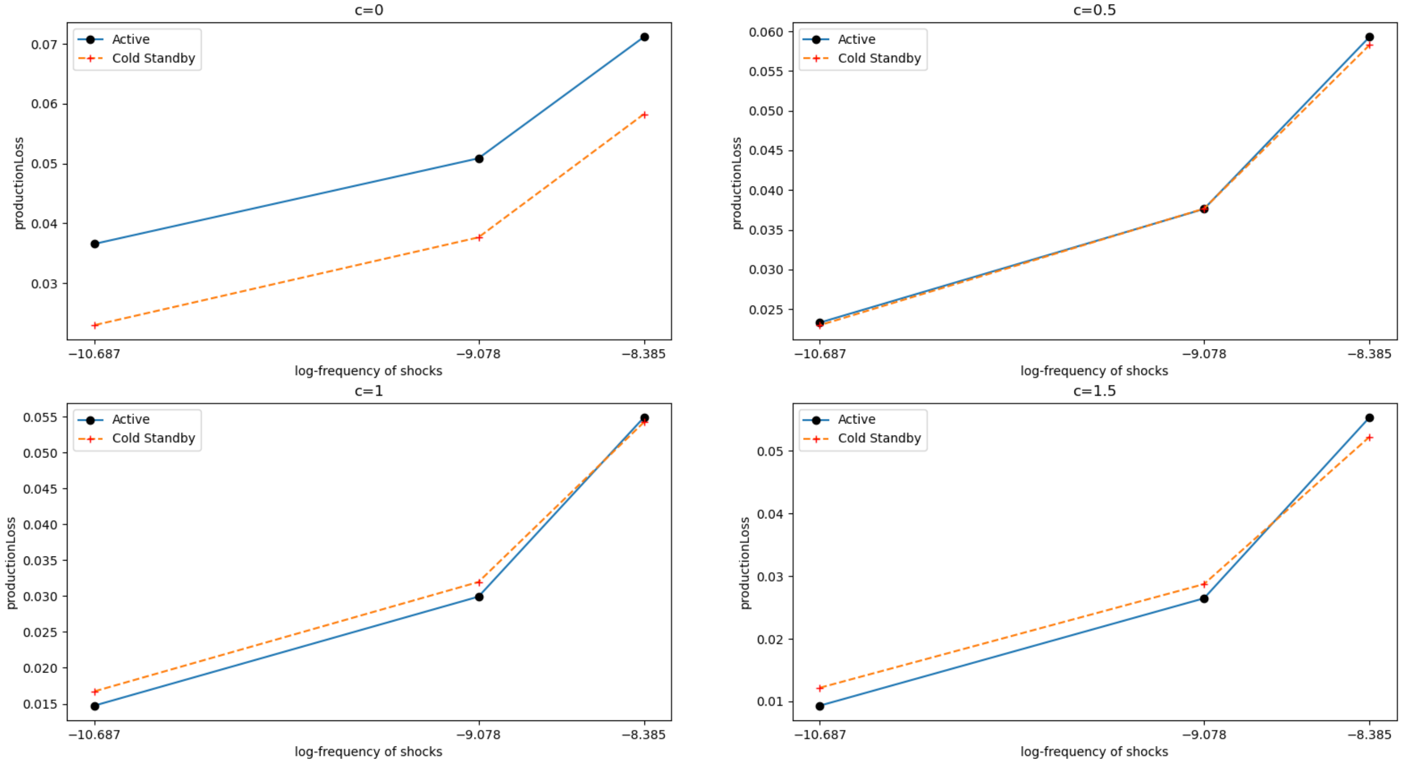
- Average production:

$$\sum_j \theta_j \, . \, j$$

  - Where θ_j is the proportion of time the system spends in states with total output j
- Average Production loss: 100 – Average production
- Frequency of shocks:
  - Once in 5 years (less frequent)
  - Once per year (medium)
  - Twice per year (high frequency)
- Monte-carlo simulation with 20000 simulations.
- Mission time: 5 years

PARAMETER	DESCRIPTION	VALUE
λ_W	Transition rate from new to degraded state	2×10^{-4}
λ_D	Transition rate from degraded to failed state	4×10^{-4}
p	Probability of switch failure	0.01
RD	Delay before repair	730

Performance Assessment



Summary

- Two redundancy strategy is assessed:
  - Active with load sharing
  - Passive with cold standby
- System performance depends on the frequency of shocks to the system but also on the degree of load sharing.
- For low frequency of shocks, active redundancy strategy has a better performance than passive redundancy especially when the degree of load sharing is high ($c \geq 1$)
- For high frequency of shocks, the passive redundancy has a better performance

Further works

- Consider a continuous degradation model. How to incorporate load sharing into such model.
- Find the optimal maintenance strategy with this model.

References

1. Ekeberg, I., Bibet, P., Knudsen, H., Reimers, Ø., and Torbergsen, E. (2022). Sand management and erosion prediction in subsea multiphase pumps. Journal of the Global Power and Propulsion Society, 6, pp.24-38. https://doi.org/10.33737/jgpps/145322
2. Yu, H., Chu, C., Châtelet, Ė. and Yalaoui, F., 2007. Reliability optimization of a redundant system with failure dependencies. Reliability Engineering & System Safety, 92(12), pp.1627-1634.
3. Olde Keizer, M. C. A., et al. (2018). "Condition-based maintenance for systems with economic dependence and load sharing." International Journal of Production Economics **195**: 319-327.

Thank you