# Health-Aware Operation of a Subsea Gas Compression System Under Uncertainty

Adriaen Verheyleweghen, Johannes Jäschke
*adriaen.verheyleweghen@ntnu.no*, *johannes.jaschke@ntnu.no*

NTNU
Norwegian University of Science and Technology

## Abstract

Subsea systems operate in harsh environments and under large uncertainties. Because they are very difficult and expensive to access, an optimal operational strategy must maximize profit, and at the same time ensure that no unplanned shutdowns occur. To achieve this, we consider a min-max robust optimization approach and a scenario-based optimization approach with recourse. Although both methods avoid unplanned shutdowns, the scenario-based method results in a less conservative solution at the cost of a larger problem size.

## Process description

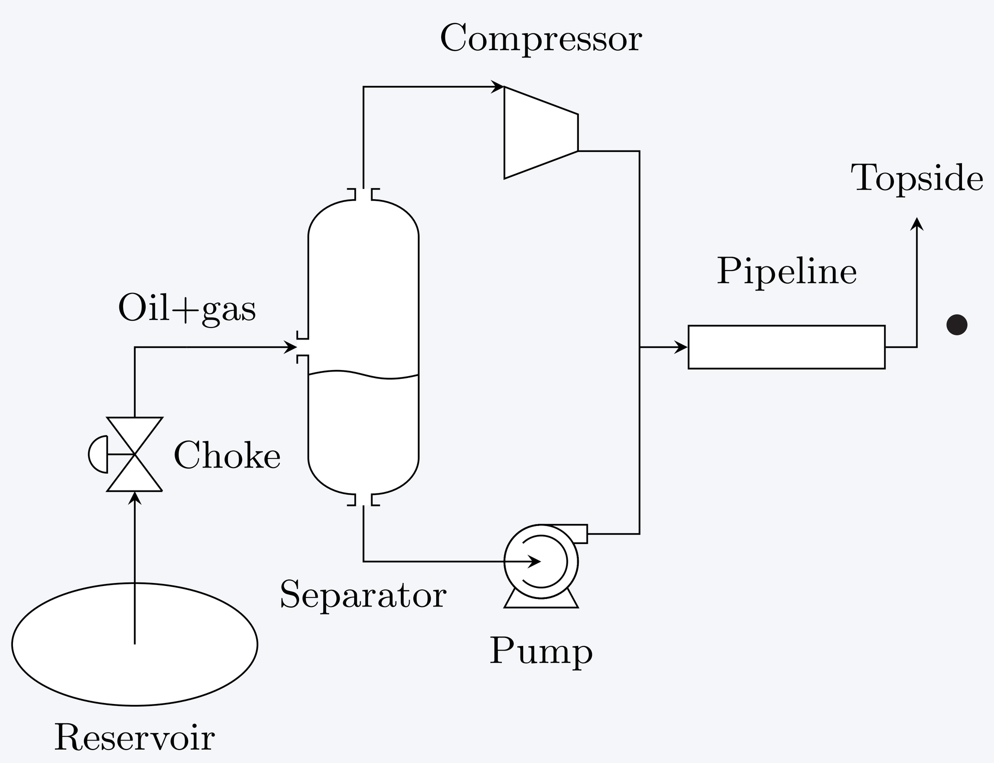


**Figure 1:** Process diagram of the subsea gas compression station.

- The process is similar to the gas compression stations installed on the Åsgard field and the Ormen Lange pilot.
- Gas and liquid are separated before being boosted to the desired outlet pressure individually. Throughput can be controlled by adjusting the well choke opening.
- The safety-critical component is the wet-gas compressor.

### Degradation of the compressor

- Result of wear and shock damage (due to setpoint changes $\Delta N$)
- Change in health is a function of compressor speed $N$

$$\Delta h = -\Big(\underbrace{p_N N^3}_{\text{Wear and tear}} + \underbrace{p_\Delta |\Delta N|^3}_{\text{Shock damage}}\Big) \tag{1}$$

**Challenge:** trade-off between degradation and production maximization.

## Conclusion

- Prognostics and control can be combined to obtain a control structure that gives economical and safe operation
- Robustness towards uncertainty is important: must solve a stochastic optimization problem
- Scenario-based method less conservative than worst-case approach, without jeaopardizing integrity

**Future work** will focus on measurement feedback and state estimation, more detailed degradation models and extension to system-wide health-aware operation.

## Combining prognostics and control

Objective: maximize expected net present value of gas production while keeping compressor healthy

$$\min_{\mathbf{u}} \ \mathbb{E}\left(-\int_0^{t_f} \text{NPV}(\dot{m}_{gas})dt\right) \quad \text{s.t.} \begin{cases}\text{Process constraints}\\ \text{Health constraints}\end{cases} \tag{2}$$

$\mathbf{u}$ : inputs (choke and compressor speed), $\mathbf{p}$ : uncertain degradation parameters: $p_N$ and $p_\Delta$

**Handling uncertainty in degradation model:**
Comparison of three methods:

1. Nominal case: Uncertainty not handled explicitly
2. Worst case: Worst possible realization of parameters
3. Scenario-based: Use five scenarios to approximate uncertainty distribution

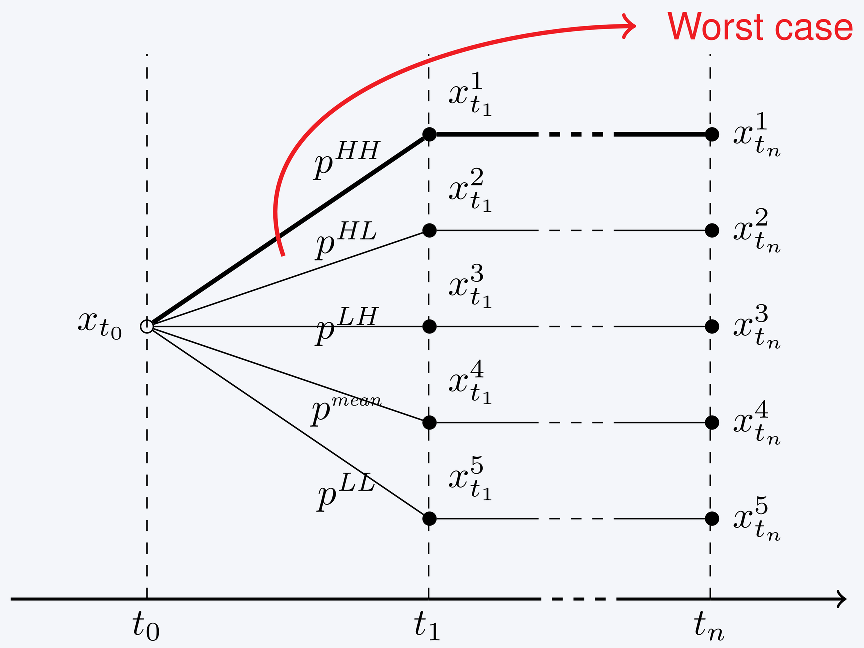


**Figure 2:** Process diagram of the subsea gas compression station.

**Table 1:** Values of the uncertain variables $p_N$ and $p_{\Delta N}$ in the scenarios used to generate the scenario tree.

| Scenario | $p_N$ | $p_{\Delta N}$ |
|---|---|---|
| *LL* | 0.006 $(\mu - 2\sigma)$ | 0.6 $(\mu - 2\sigma)$ |
| *LH* | 0.006 $(\mu - 2\sigma)$ | 1.8 $(\mu + 2\sigma)$ |
| *HL* | 0.018 $(\mu + 2\sigma)$ | 0.6 $(\mu - 2\sigma)$ |
| *HH* | 0.018 $(\mu + 2\sigma)$ | 1.8 $(\mu + 2\sigma)$ |
| *mean* | 0.012 $(\mu)$ | 1.2 $(\mu)$ |

## Results

- Scenario-based method outperforms the worst-case method
- Nominal case: health constraint and discharge pressure constraint are violated

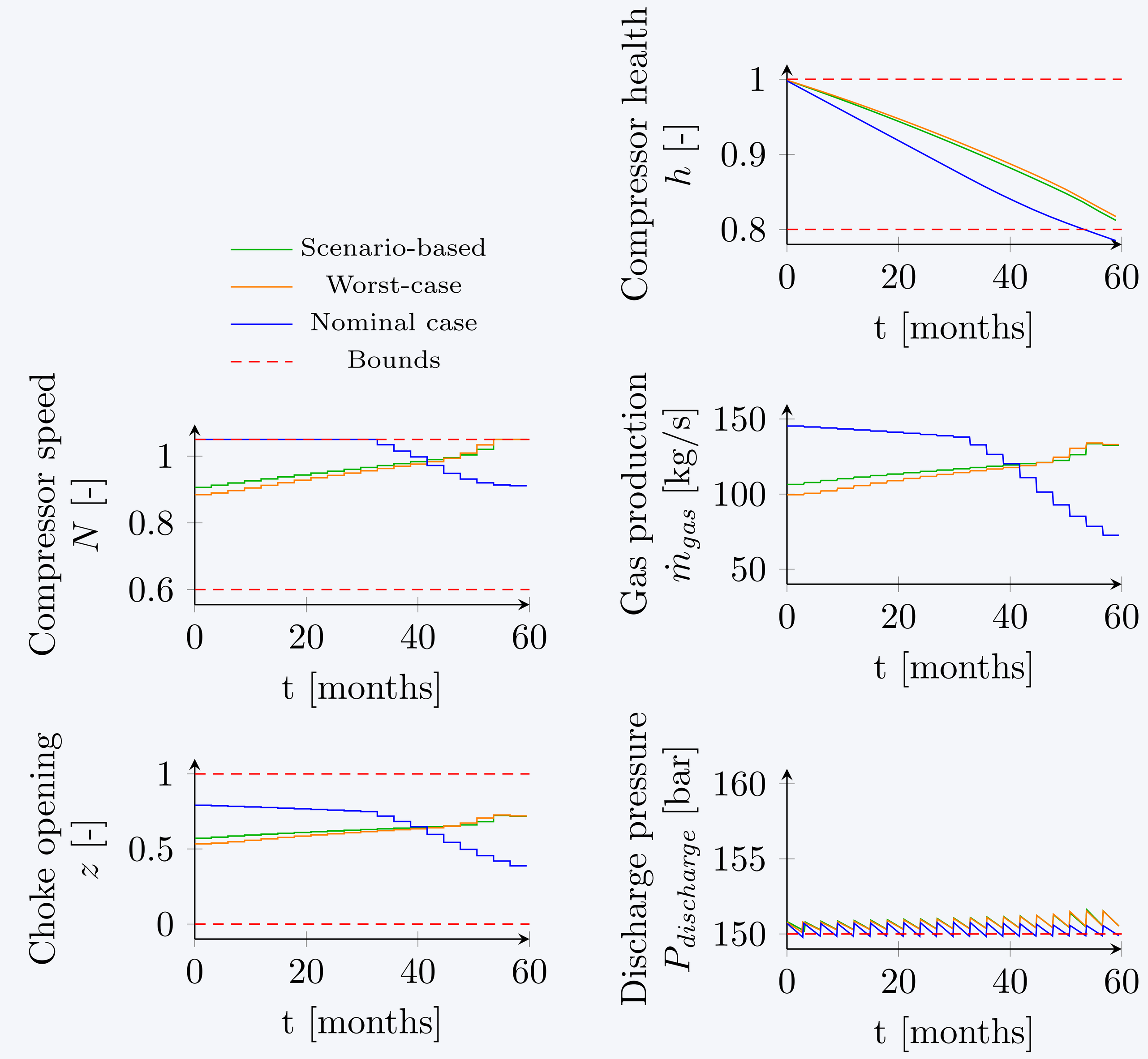


**Figure 3:** Comparison of closed-loop performance of three different controllers in the presence of uncertainty. The realizations of the uncertain variables are $p_N = 0.015$ and $p_\Delta = 1.5$.

**Table 2:** Normalized profit, i.e. net present gas production, for the three methods (in closed-loop).

| Method | Discounted closed-loop profit |
|---|---|
| Scenario-based | 1.026 |
| Worst-case | 1.000 |
| Nominal case | 1.056* |

* Constraint violation

## References

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