Combined Maintenance Scheduling and Production Optimization

SUBPRO

sfi Centre for Research-based Innovation
The Research Council of Norway

NTNU

Adriaen Verheyleweghen *verheyle@ntnu.no*

Himanshu Srivastav *himanshu.srivastav@ntnu.no*

Anne Barros *anne.barros@ntnu.no*

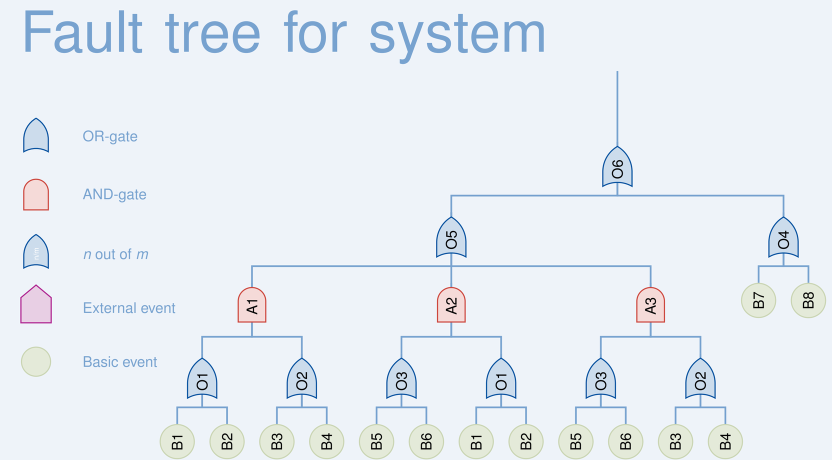
Johannes Jäschke *jaschke@ntnu.no*

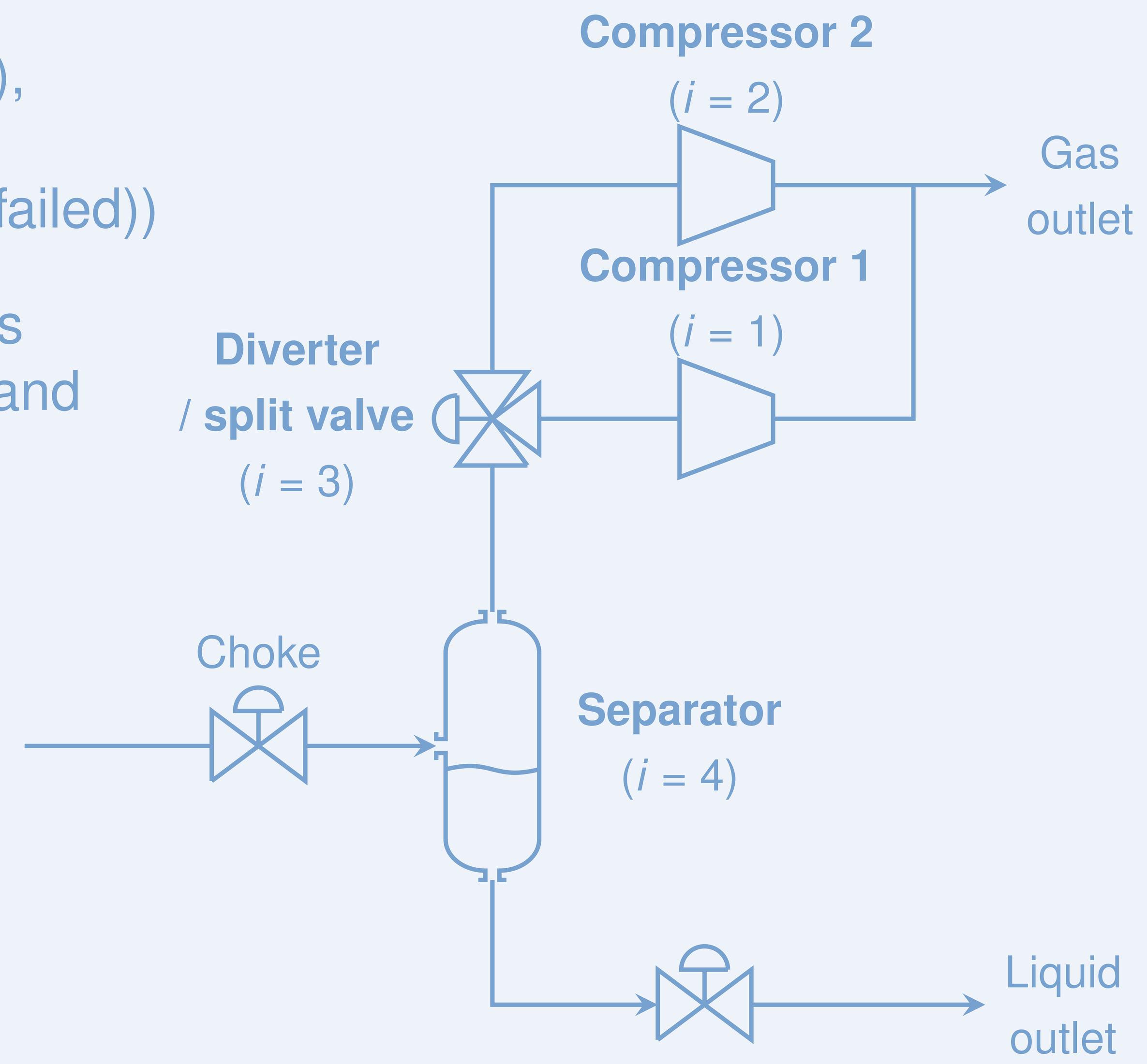
Motivation

- **How to optimize production and also find optimal non-periodic inspection and maintenance schedule?**
- Too many decision variables: Monte-Carlo simulations of Markov chain are too slow
- Formulate problem as numerical optimization problem instead

Case study: subsea gas compression

- Four reliability-critical components (i), each described by four discrete degradation states (A, B, C and F (failed))
- Optimization objective: maximize gas production and minimize inspection and maintenance costs
- Fault tree for system

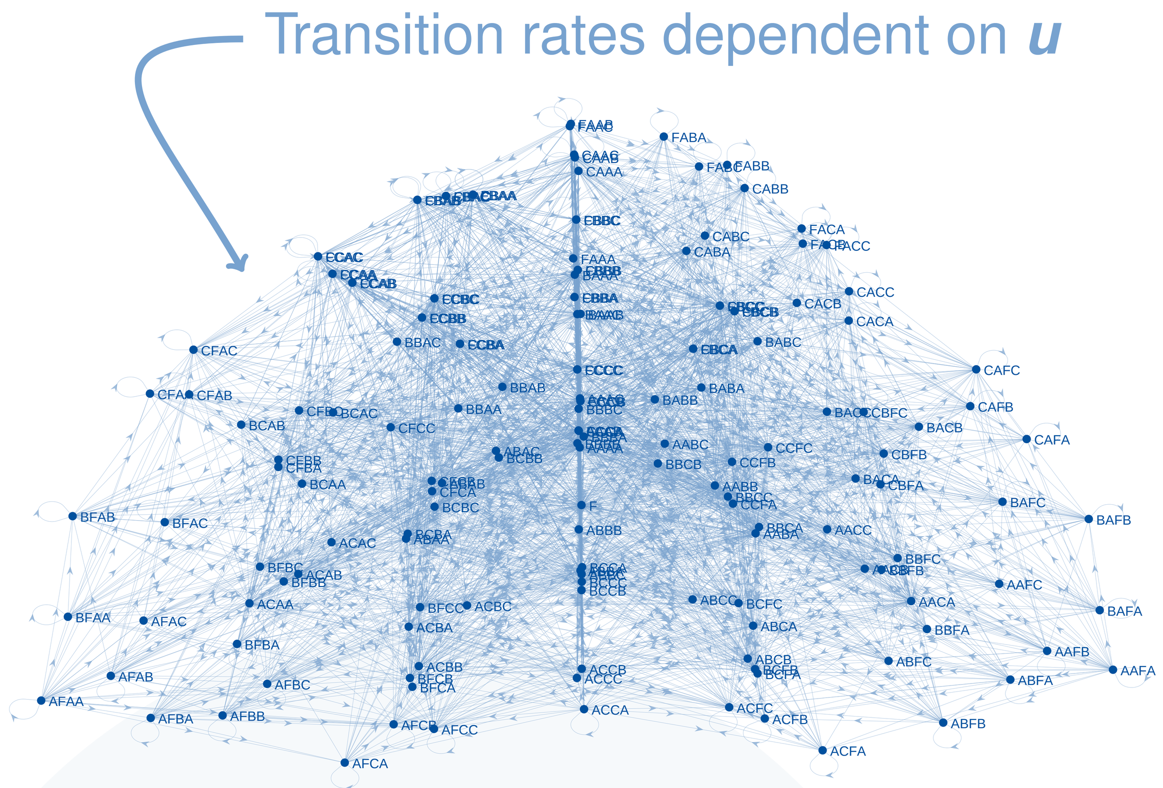




Markov chain for the case study

- 163 states
- 945 edges
- Continuous decision variables

⇒ Huge search space, MC simulations practically infeasible



1. Model evolution of system state probabilities between inspections as function of inputs

Before inspection: $\dot{\boldsymbol{x}} = f_1(t, \boldsymbol{x}, \boldsymbol{u})$

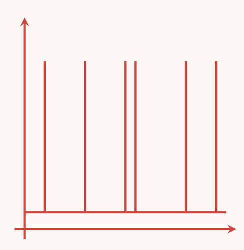
Reset initial condition according to AGAN policy

After inspection: $\dot{\boldsymbol{x}} = f_2(t, \boldsymbol{x}, \boldsymbol{u})$

2. Combine into single master equation with reset term

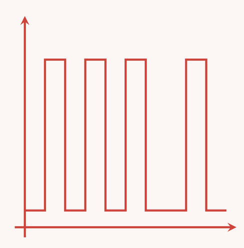
$$\dot{\boldsymbol{x}} = \frac{d\boldsymbol{x}}{dt} = f(t, \boldsymbol{x}, \boldsymbol{u}) + Rr$$

Rr term is non-smooth, determines when to reset state



3. Introduce necessary approximations to make problem numerically tractable

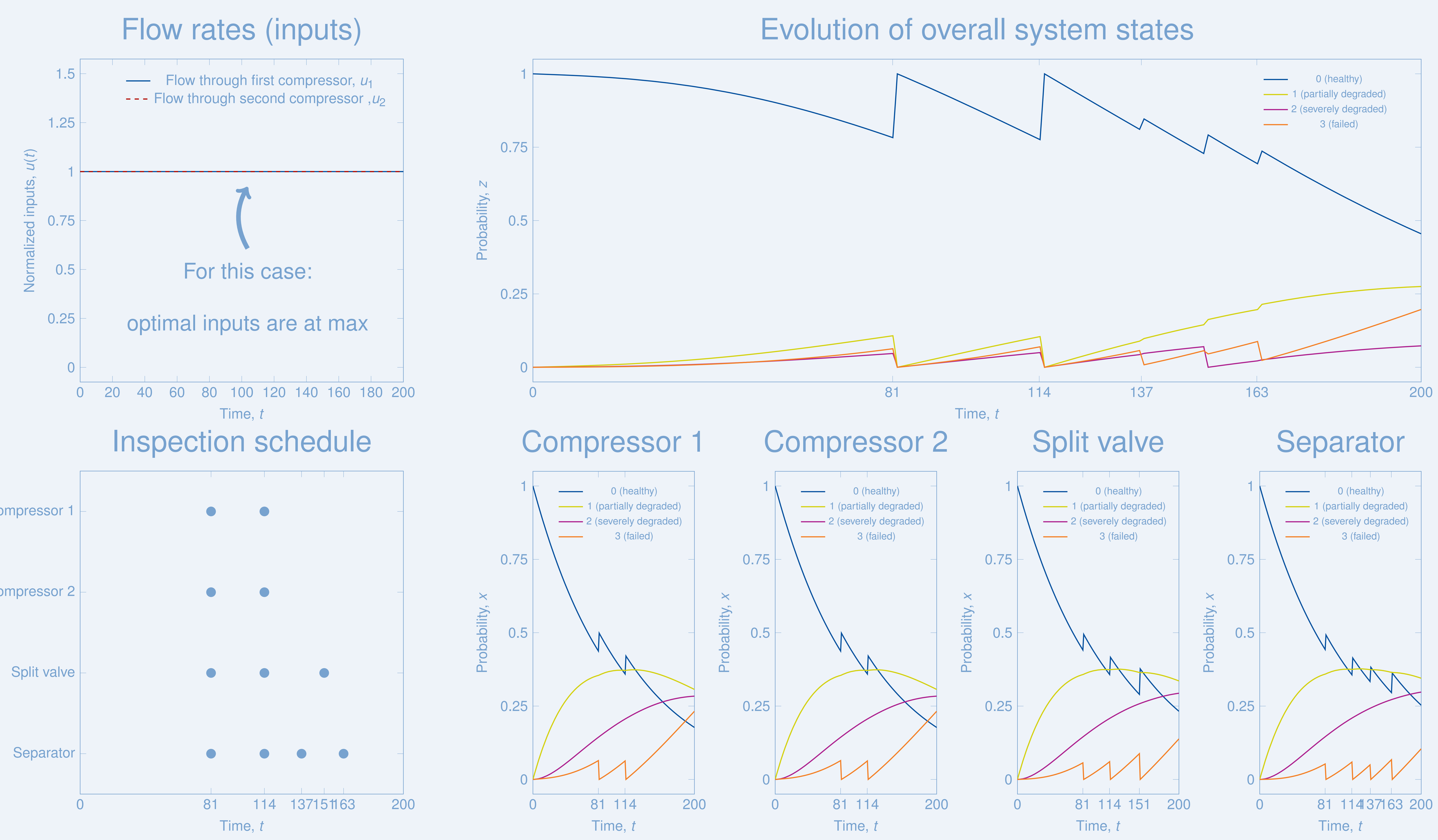
Approximate Rr by Box-car function to get continous opt. problem



4. Discretize differntial eq. and solve resulting NLP using off-the-shelf NLP solver

$$\min_{\boldsymbol{r},\boldsymbol{u}} \int_0^{t_f} \phi(\boldsymbol{x})dt \quad \text{s.t.} \quad \dot{x} = f(t, \boldsymbol{x}, \boldsymbol{u}) + Rr \longrightarrow \min_{\boldsymbol{r},\boldsymbol{u}} F(z) \quad \text{s.t.} \quad c(z) = 0, \; g(z) \leq 0$$

Case study: simulation results



Conclusions

- We have developed an optimization-based method for production optimization and maintenance scheduling
- No need for Monte Carlo simulations
- Can be solved with off-the-shelf NLP solvers after some reformulations

Download paper with references here: