Robust Optimization for Grade Transitions In Polyethylene Solution Polymerization

Jun Shi[1], Lorenz T. Biegler[1]

Intan Hamdan[2], Sarat Munjal[2], John Wassick[2], Scott Bury[2], Shawn Feist[2], Alex Kalos[2]

[1]Center of Advanced Process Decision-making
Department of Chemical Engineering
Carnegie Mellon University

[2]The Dow Chemical Company

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Background and Motivation

LLDPE Solution Polymerization[1]

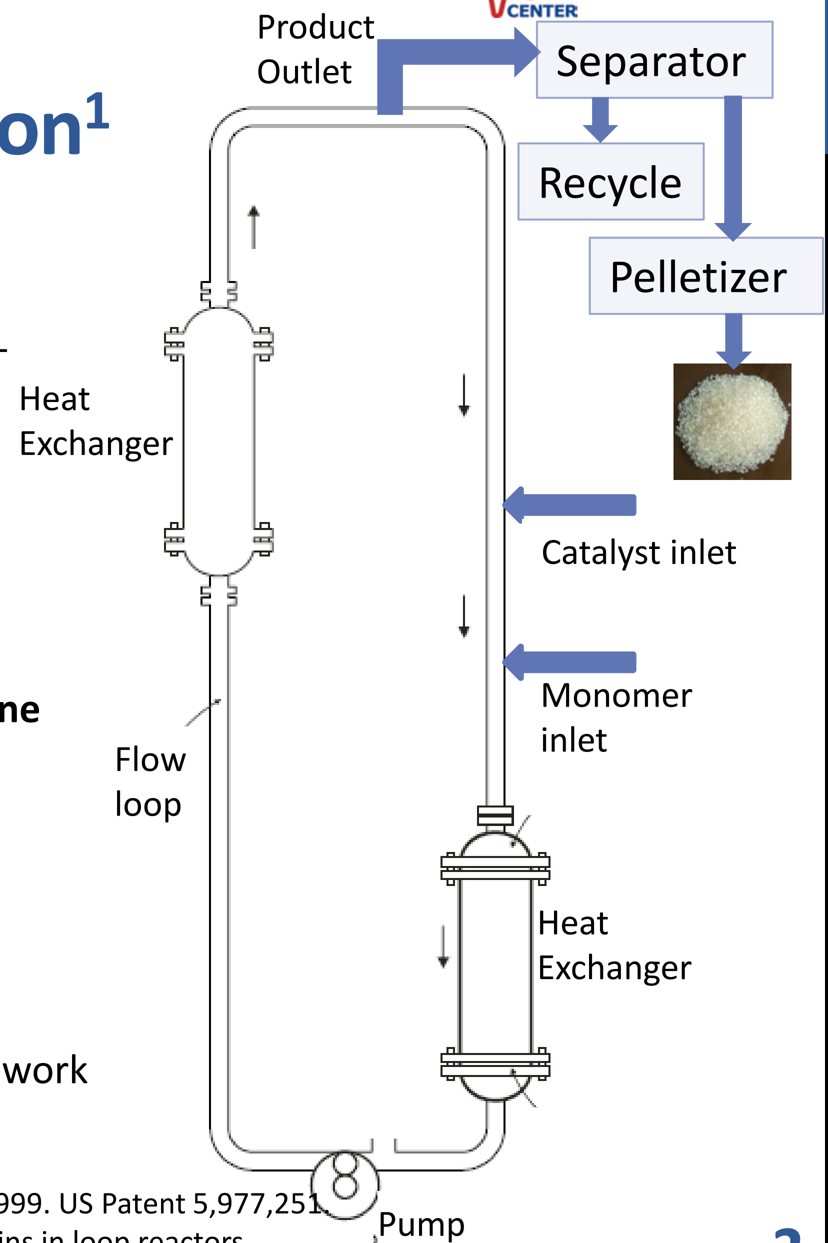
- Linear low-density polyethylene (LLDPE)
- Made by copolymerization of ethylene with longer-chain olefins (octene, butene, hexene, propylene)
- Long loop with heat exchangers
- Continuous operation with multiple feed positions

Current Practice

- Different grades produced in **a single production line** and grade transition takes **a long time**
- Hard to implement complex transitions
- Room for improvement

Objectives

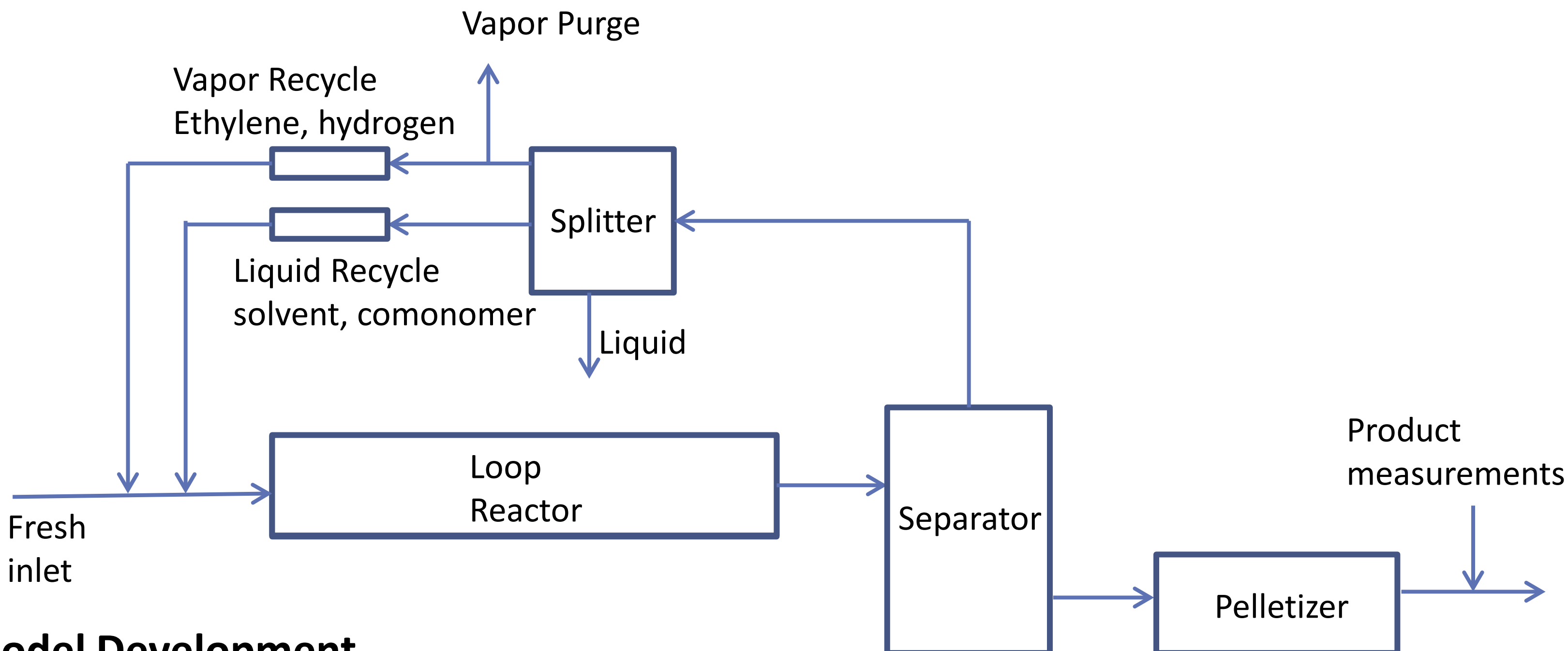
Develop a model based control and optimization framework to minimize **transition time** and **offgrade products**



1. Che I Kao et al. Non-adiabatic olefin solution polymerization, November 2 1999. US Patent 5,977,251.
2. J.J. Zacca and W.H. Ray. Modelling of the liquid phase polymerization of olefins in loop reactors. Chemical Engineering Science, 48(22):3743–3765, 1993.

Project Progress

Model Development and Offline Optimization



Model Development

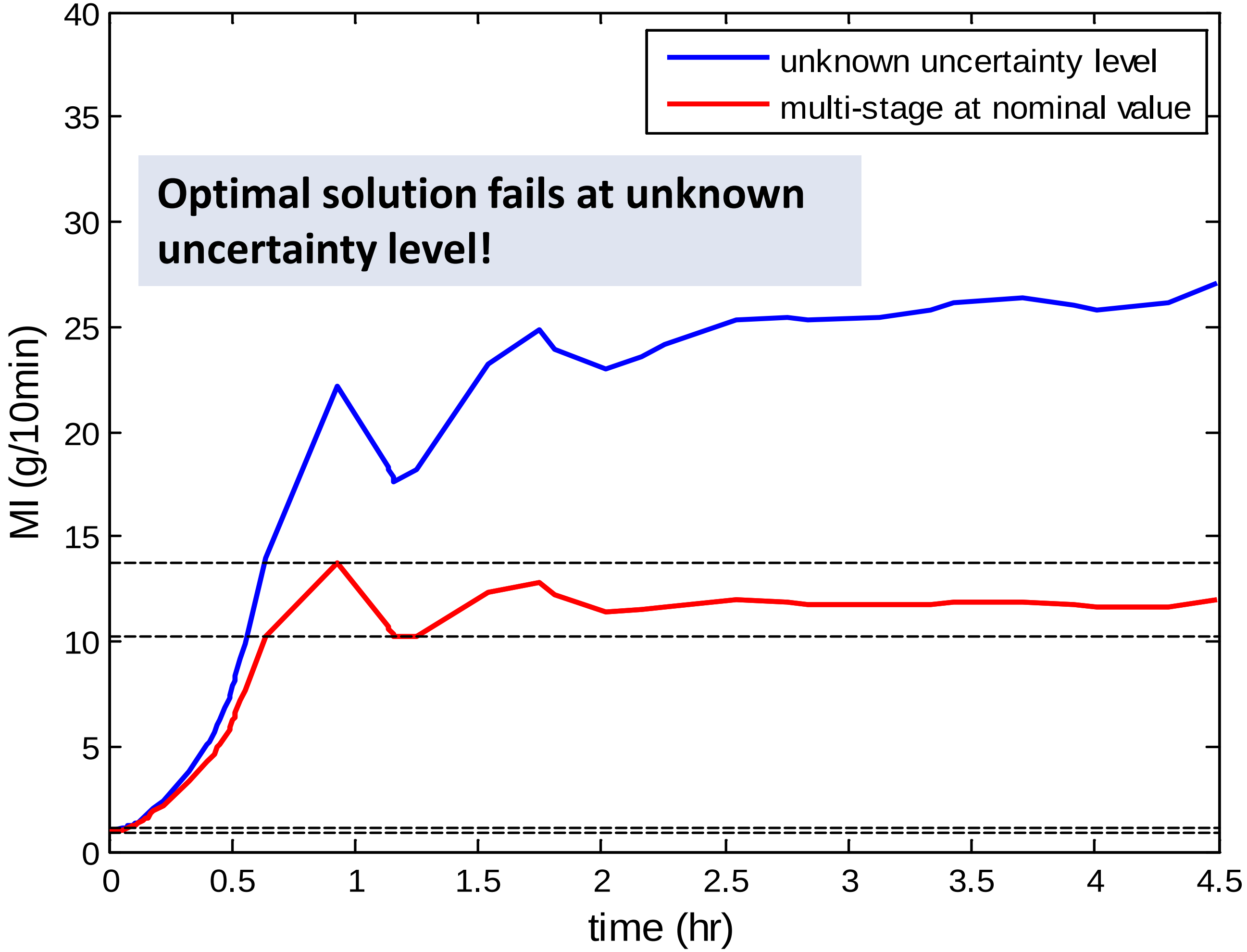
- CSTR with ***data-driven surrogate VLE model***
- ***Method of moments*** for product property prediction
- ***Variable time delay*** for recycle streams
- Process constraints

Offline Dynamic Optimization

- Single stage optimization (single value target)
- ***Multistage*** optimization (specification bands)

To Lower Density and Higher MI

Comparison of MI Profile



Methodology

Concept of backoff

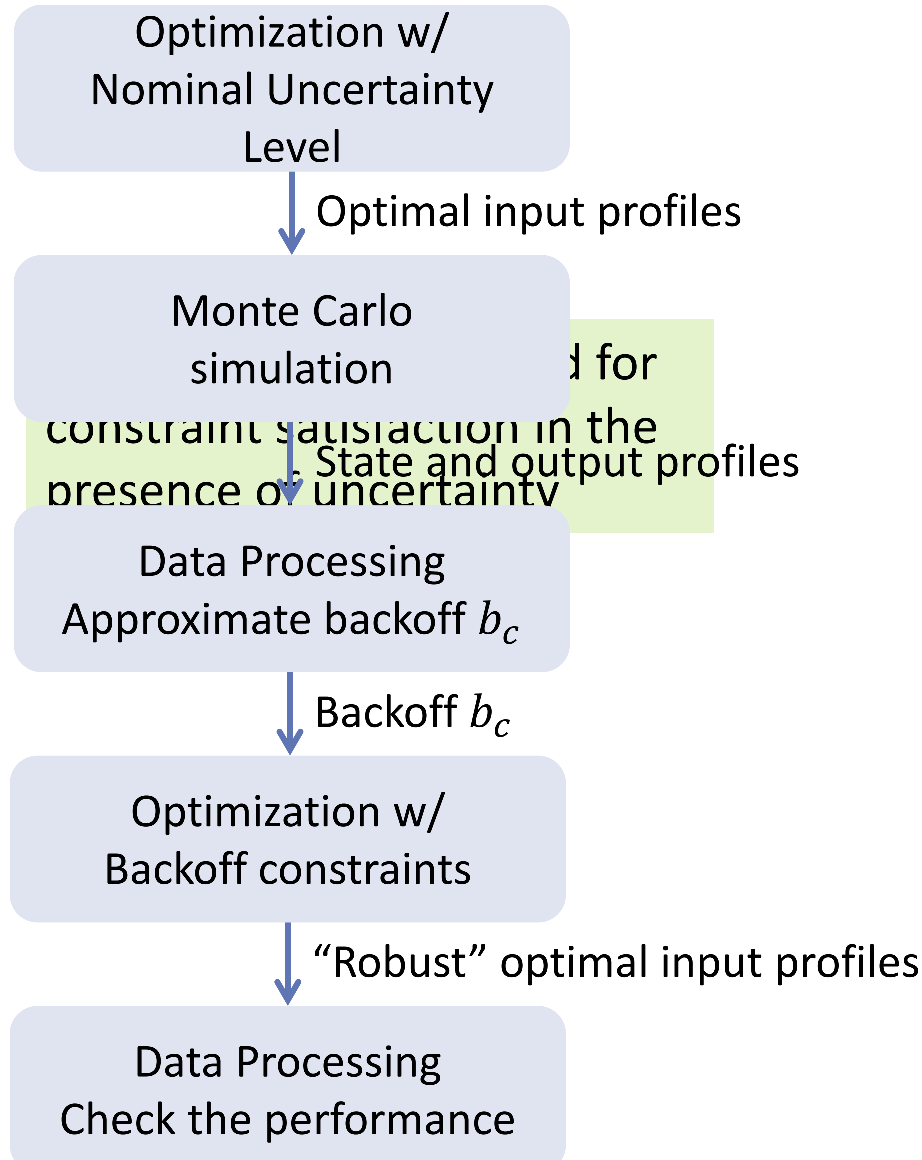
Original constraints

$$f(x,u,p) \leq 0$$

Updated inequality constraints

$$f(x,u,\bar{p}) + b_c \leq 0$$

Nominal value



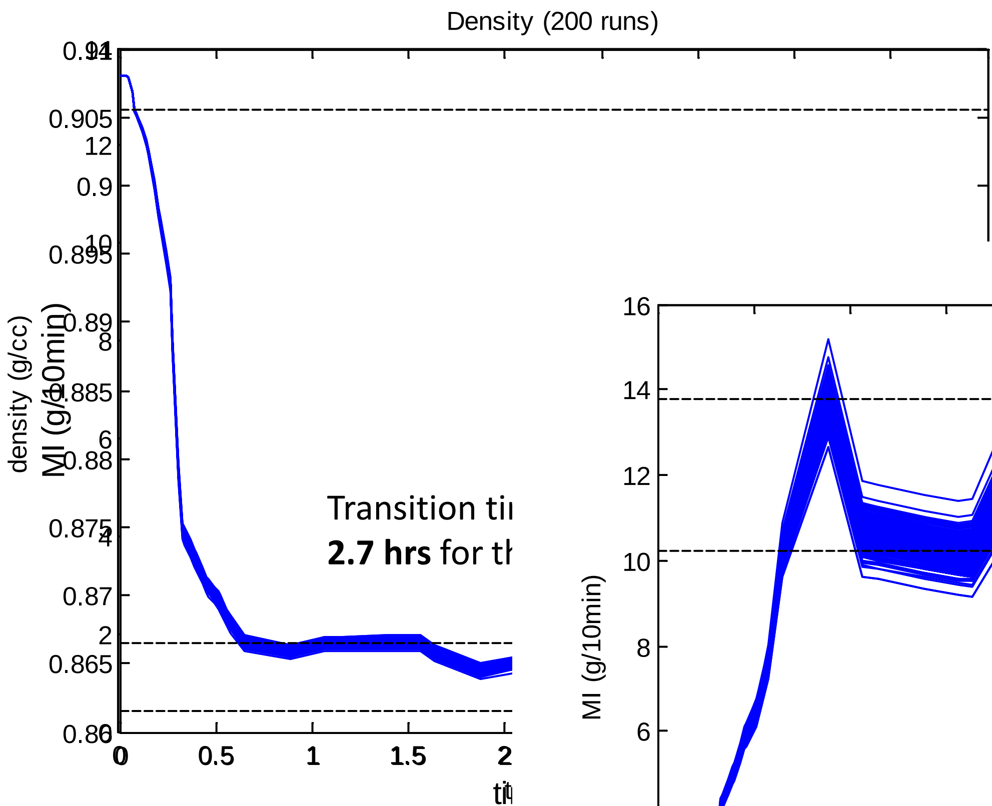
Monte Carlo simulation to approximate b_c

- Assume the uncertainty p is in a range around its nominal value and it follows normal distribution $\mathrm{N}(p_0, \sigma^2)$
- Assume 5% of p_0 is within 3σ
- m=200 in the following case study

4. Srinivasan, B., Bonvin, D., Visser, E., & Palanki, S. (2003). Dynamic optimization of batch processes: II. Role of measurements in handling uncertainty. *Computers & Chemical Engineering*, *27*(1), 27-44.

Case study

Nominal Optimal Solution / Monte Carlo Simulation



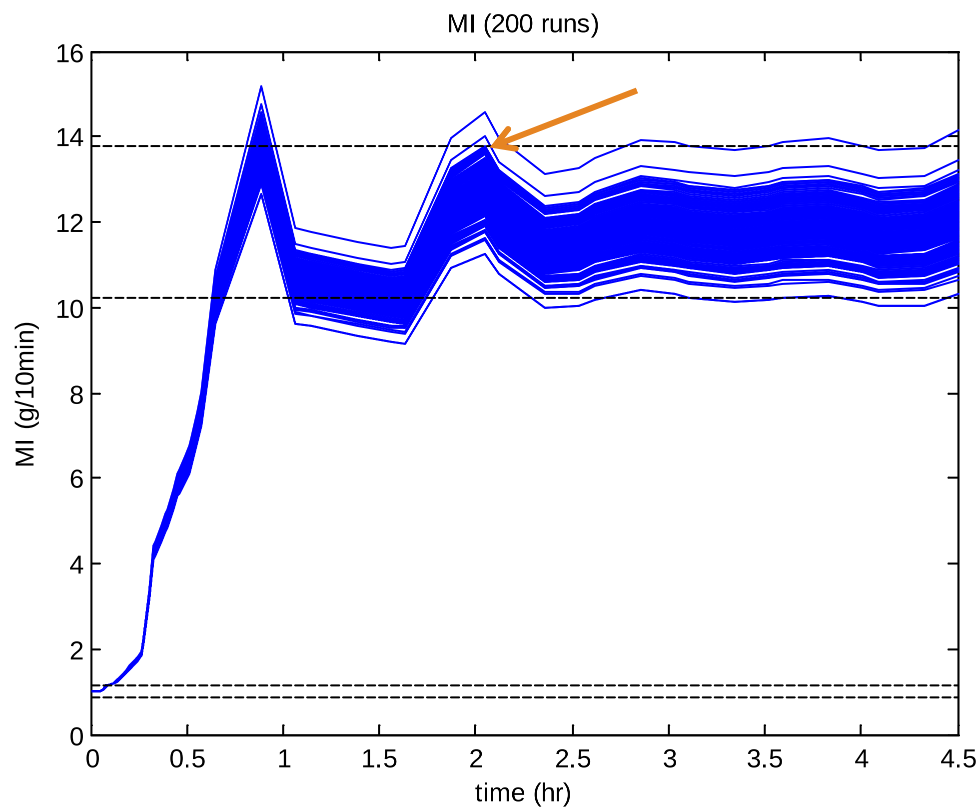
Optimization w/ Nominal Uncertainty Level

Optimal input profiles

Monte Carlo

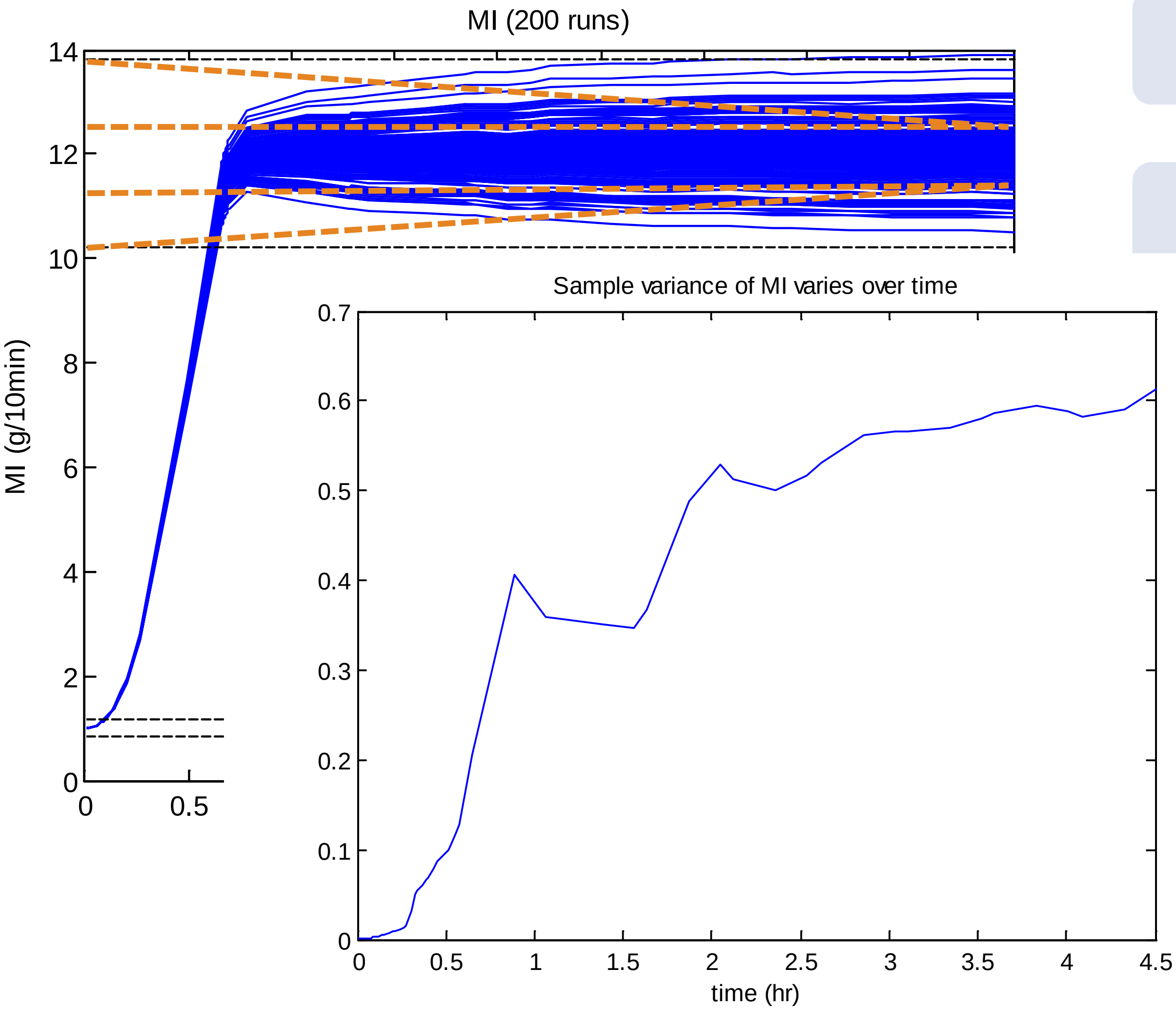
d output profiles

nput profiles



Case study

Approximate backoff b_c



Optimization w/ Nominal Uncertainty Level

↓ Optimal input profiles

Monte Carlo simulation

↓ Resulting state and output profiles

ta Processing
ximate backoff b_c

↓ Backoff b_c

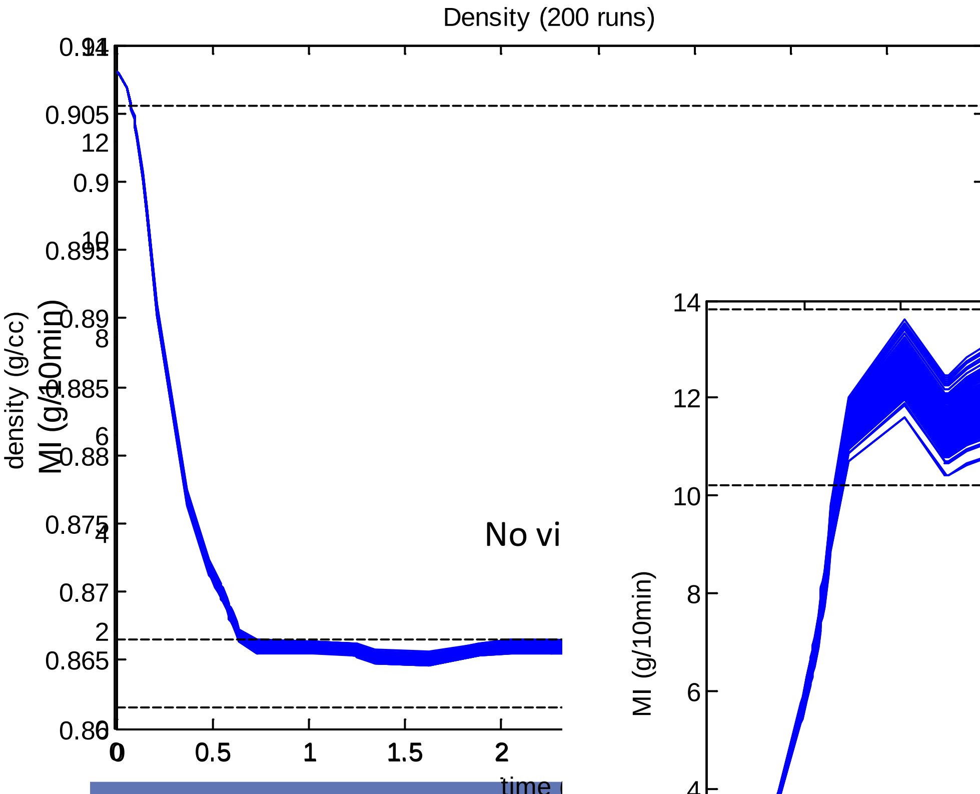
timization w/
koff constraints

↓ “Robust” optimal input profiles

ta Processing
the performance

Case study

Optimization with uncertainty
Performance with backoffs



Optimization w/ Nominal Uncertainty Level

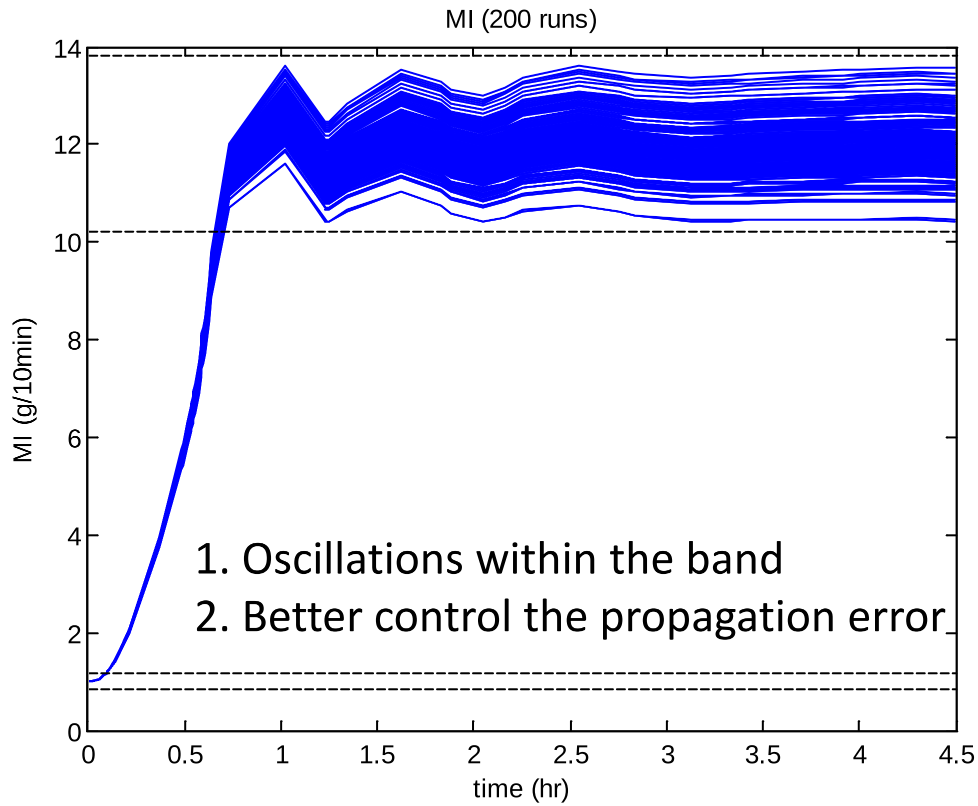
Optimal input profiles

Monte Carlo

tput profiles

t profiles

in min
Multistage w/o backoffs
Multistage w/ time-varyin



Significance

Developed a rigorous dynamic model for the process

- Built and integrated a surrogate VLE model
- Predicts accurately with reduced model complexity

Single-stage formulation vs. multistage formulation

- Takes specification bands into account
- Minimizes transition time and off-grade product directly
- Greatly reduces the transition time and the off-grade production

Robust optimization using backoff constraints

- Computationally tractable optimization with time-varying backoffs
- Robust transition policies

Potential Value and Future Work

Potential Value

- **Reduction** of transition time and off-grade product
- **Guided** complex transitions
- Increased **flexibility** in production wheel
- **Robust** offline transition policies

Future Work

- **Improve the performance** by tuning parameters and refining the model
- Apply **adjoint sensitivity formulation** for optimization under uncertainties
- Consider **online** optimization and model predictive control

Thanks for your attention!