Integrated Scheduling and Dynamic Optimization of Batch Processes Using State Equipment Networks

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Introduction

Background and motivation

- The current status quo of batch scheduling and operations
  - Batch process scheduling: recipe-based approaches
    - ⋆ Decoupled scheduling and unit operations
    - ⋆ Dow's practice: Discrete-time resource-task network [1]
    - \+ Easy (linear) models for scheduling
    - − Poor process flexibility
    - − Loss of process profitability

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- Integration of scheduling and dynamic optimization
  - Adding value to existing assets
  - Improving plant reliability

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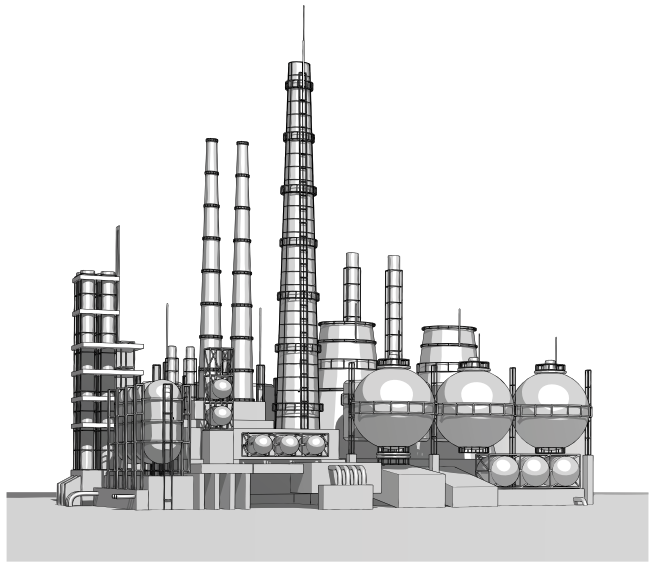
Introduction

Problem description

- Given
  - A batch plant with existing equipment
  - A time horizon to make products
  - Dynamic models of process operations
- Determine
  - The optimal production schedule
  - The optimal equipment control strategy
- Via
  1. Process representation using the state equipment network(SEN)
  2. Mathematical optimization formulation



Solution Strategy

Integrated optimization based on the SEN

- The SEN represents the process system as a directed graph connecting two kinds of nodes

Material	Feed, intermediate and final products
Equipment	Process units carrying out operations

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- The integrated formulation

Objective function Max Profit = Product sales - Material cost - Operating cost

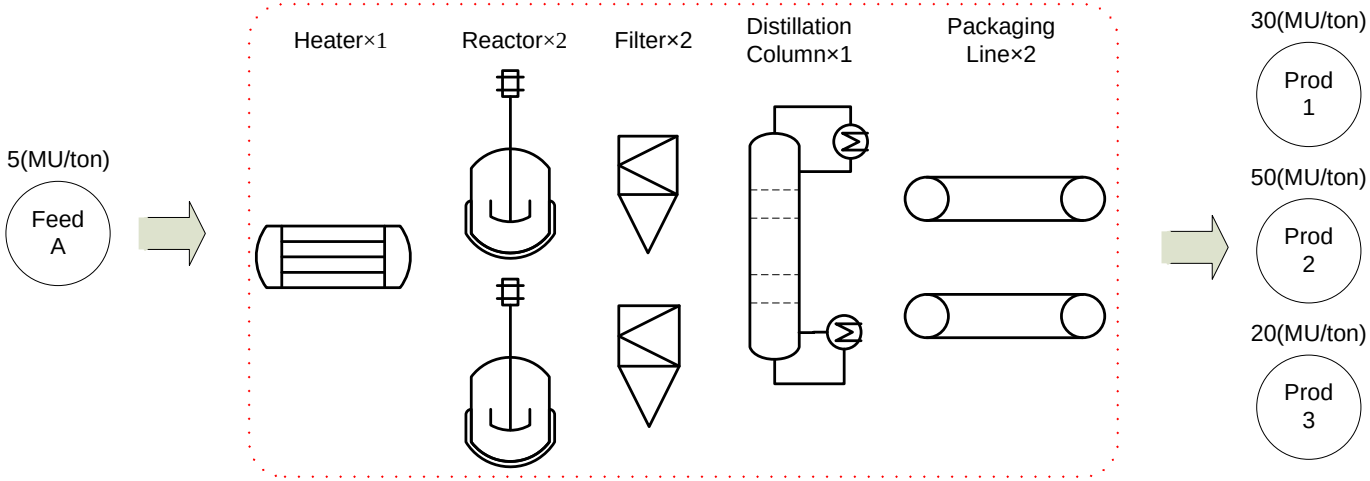
Constraints

- **Scheduling considerations**
  Assignment constraints, material balance, capacity constraints, timing constraints
- **Unit operation**
  Dynamic first-principle models, limits on controls and states
- **Material quality measurement**
  Material blending, quality requirements
- **Auxiliary tightening constraints**
  Tightening timing constraints, mass balance of process units

Case Study

A jobshop batch plant

- Equipment units and products manufactured in the plant



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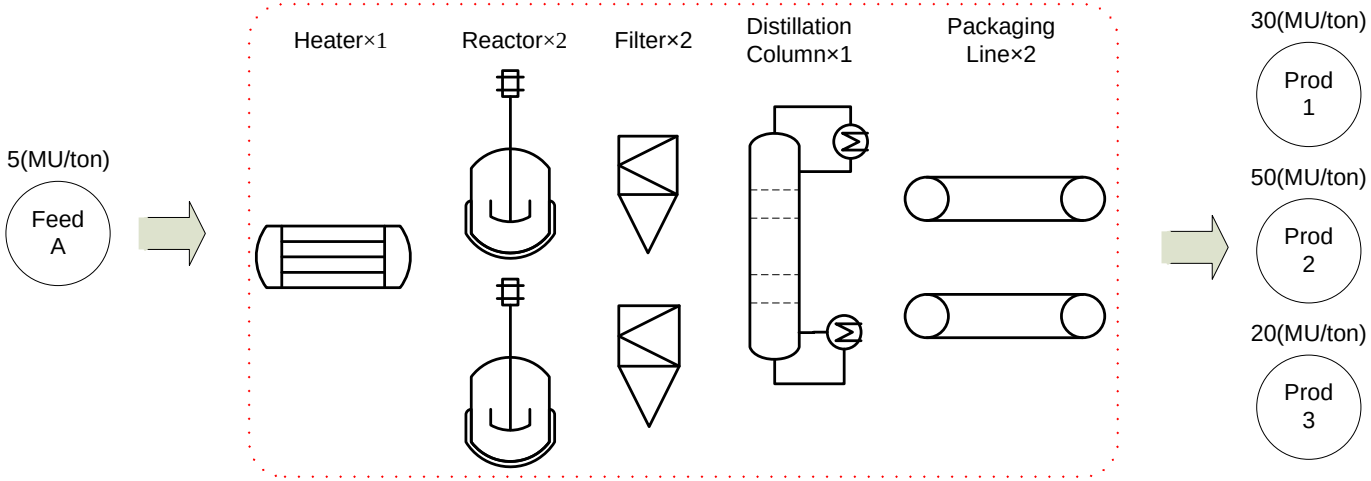


- Maximizing the net profit within a 10-hour time horizon

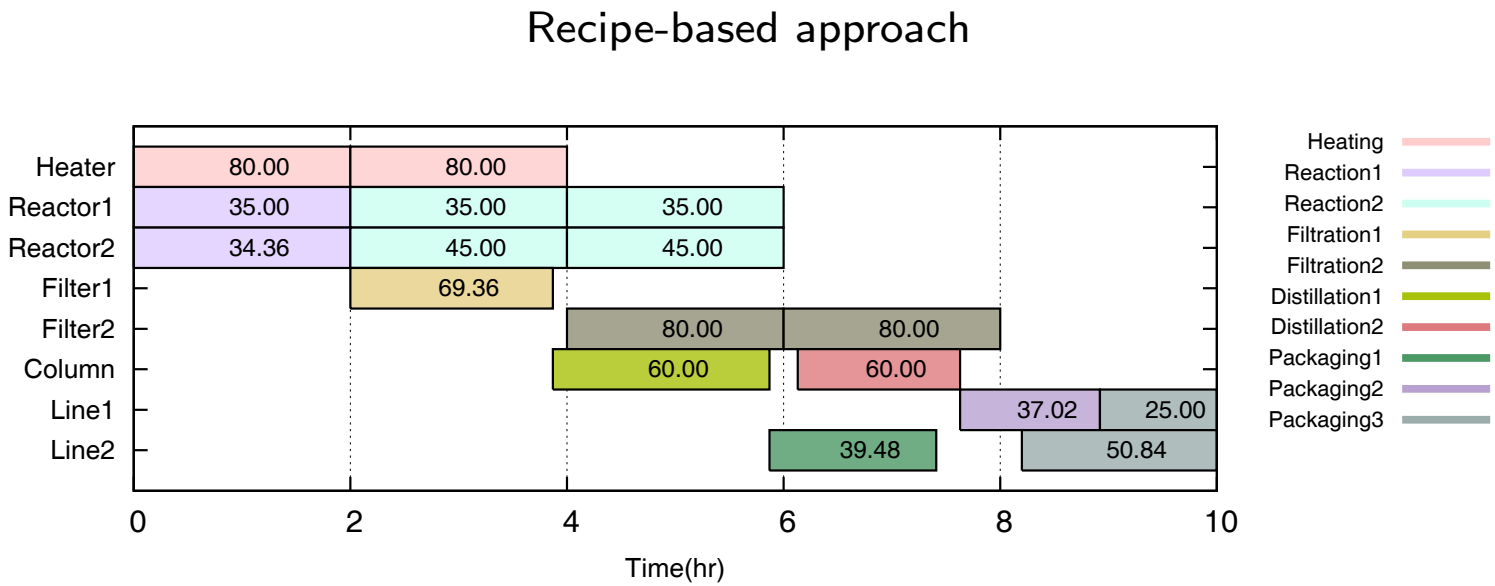
Model	Statistics			
	Type	Var.(Discrete) #	Nonlinear Var. #	Cons. #
Recipe-based	MILP	676(90)	0	1079
Integrated	MINLP	4978(90)	2292	12507

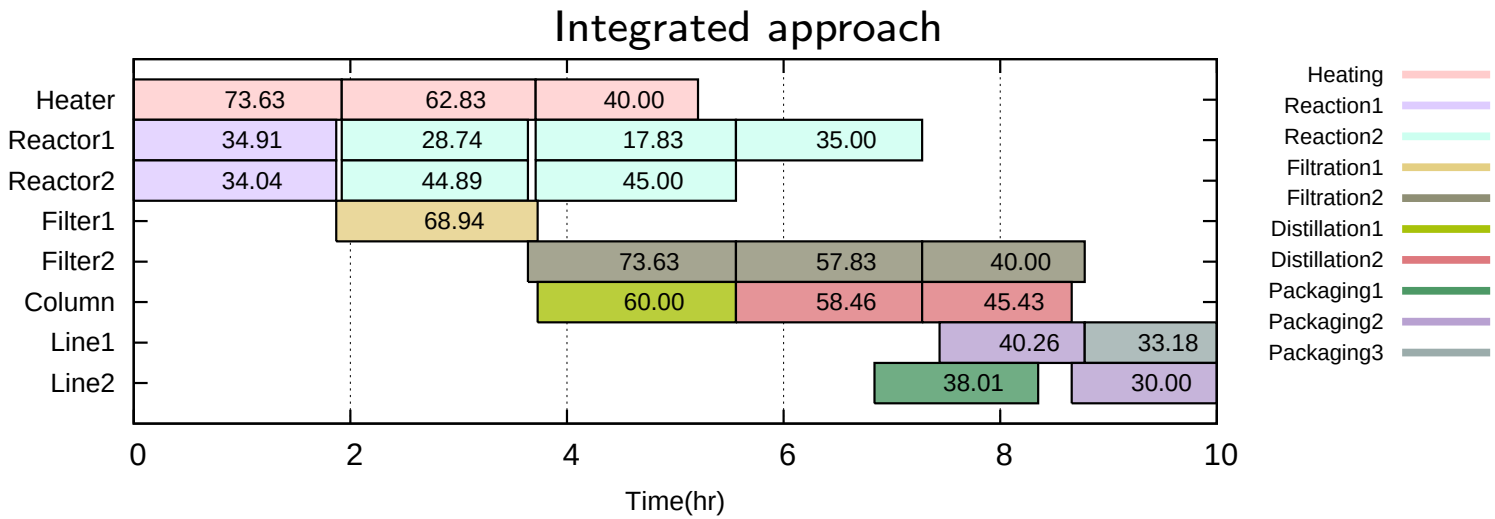
Model	Solution			
	Profit(MU)	CPU time (s)	Node(Best) #	Gap(%)
Recipe-based	1374	0.366	288(199)	0.0
Integrated	1935	9564	5000(1602)	67.9

MILP solved by CPLEX, MINLP solved by SBB(CONOPT)

Case Study

Optimal production schedules in Gantt charts



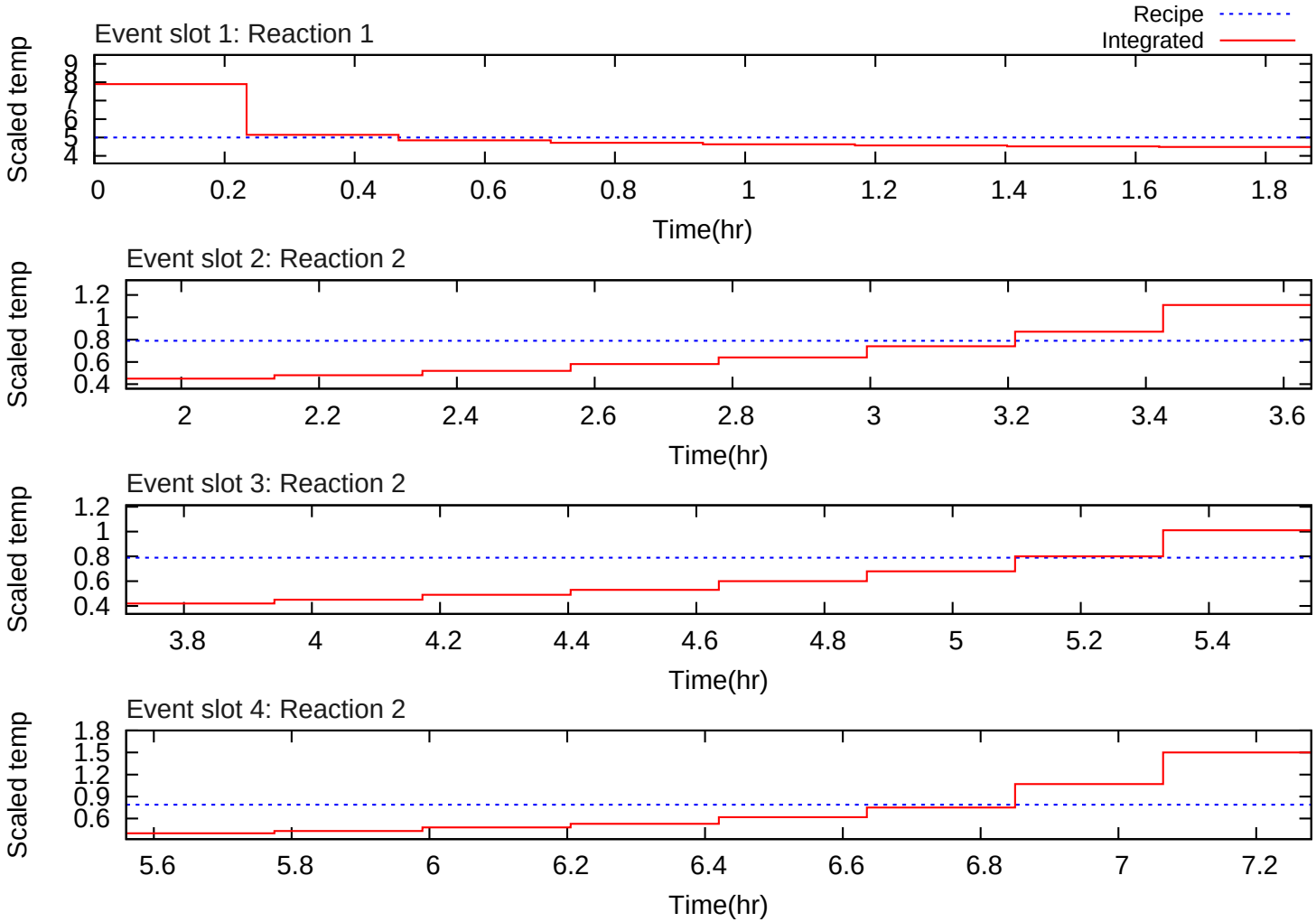


Numbers inside slots are batch sizes

Case Study

Optimal operating profiles for batch units

- Optimal temperature profiles of *Reactor 1*



Dynamic profiles also obtained for *Reactor 2* and *Distillation Column*

Conclusions and Acknowledgments

- Concluding remarks
  - The *state equipment network* representation of batch processes
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- Future work

  Off-line$\rightarrow$On-line
  - Alternative scheduling formulations
  - Data-driven dynamic models

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  - Alternative scheduling formulations
  - Data-driven dynamic models
- Thank you

  I am glad to take questions...