C3 Feedstock Optimization for Multiproduct Polypropylene Production

Pablo A. Marchetti, Ignacio E. Grossmann
Department of Chemical Engineering
Carnegie Mellon University

Wiley A. Bucey, Rita A. Majewski
Braskem America

Center for Advanced Process Decision-making
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Project Overview

Polypropylene production facility

- Chemical and refinery grade feedstocks with different prices and propylene purities.
- Best operation will balance production rate with costs of feedstocks, maximizing plant throughput.

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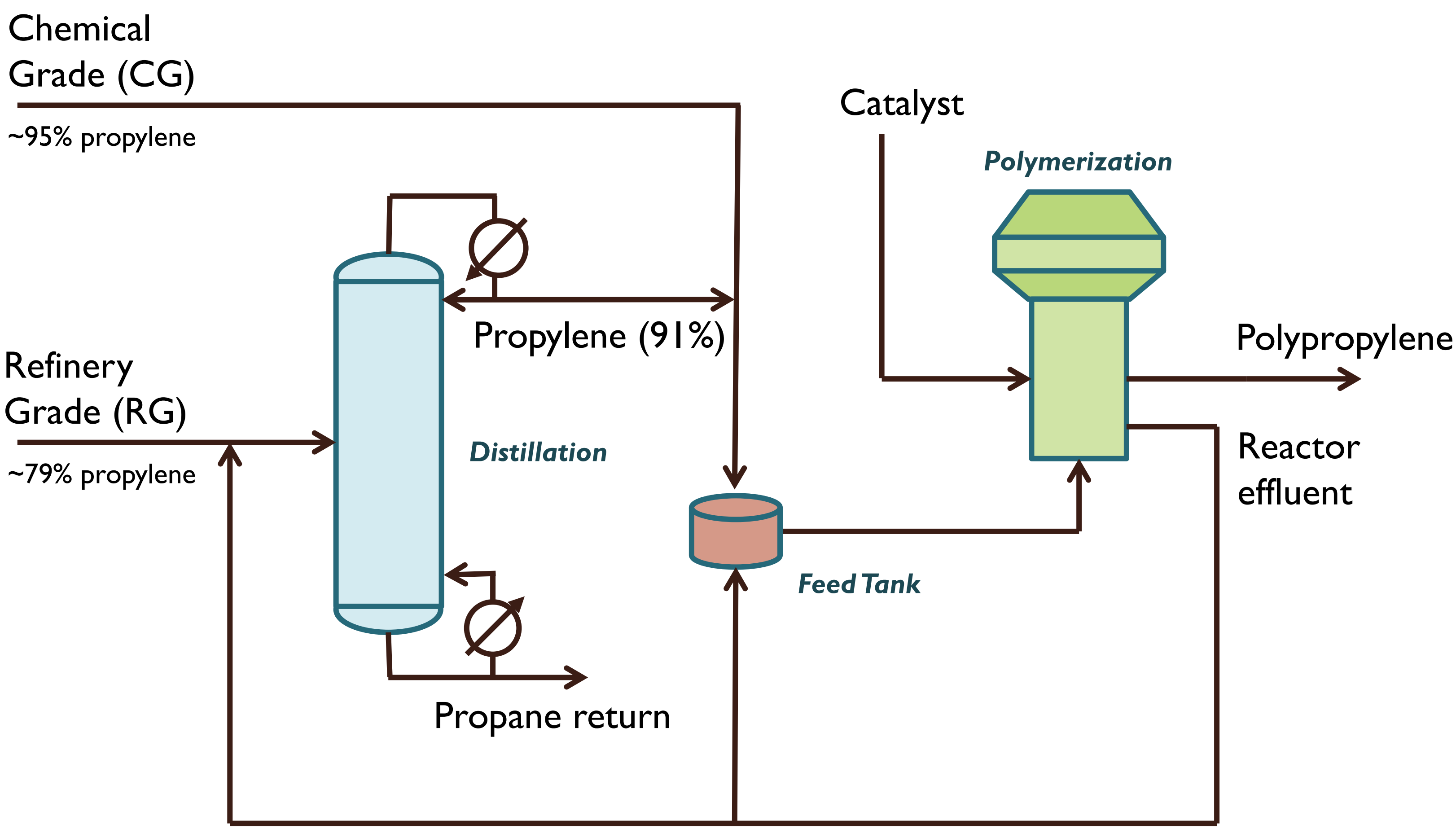
- Objectives:
  - Development of a Non-linear Programming (NLP) model to maximize benefits by obtaining a better balance of RG and CG feedstocks for single or multiple production orders.
  - Determine operation rates for a schedule of multiple production orders within a 3-month timeframe.
  - Implement user-friendly interface (GAMS model / MS-Excel)

Process and Problem Description



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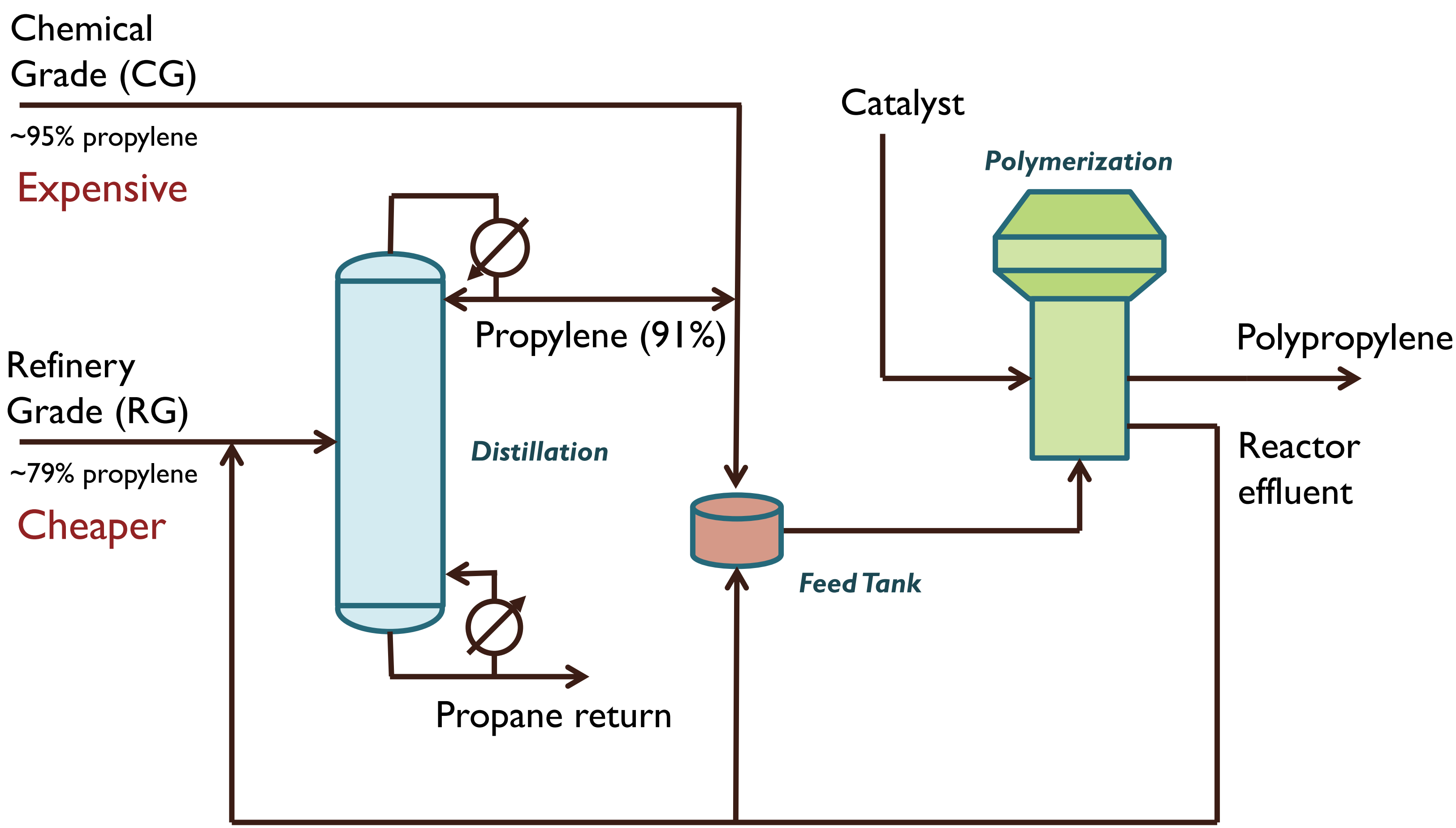

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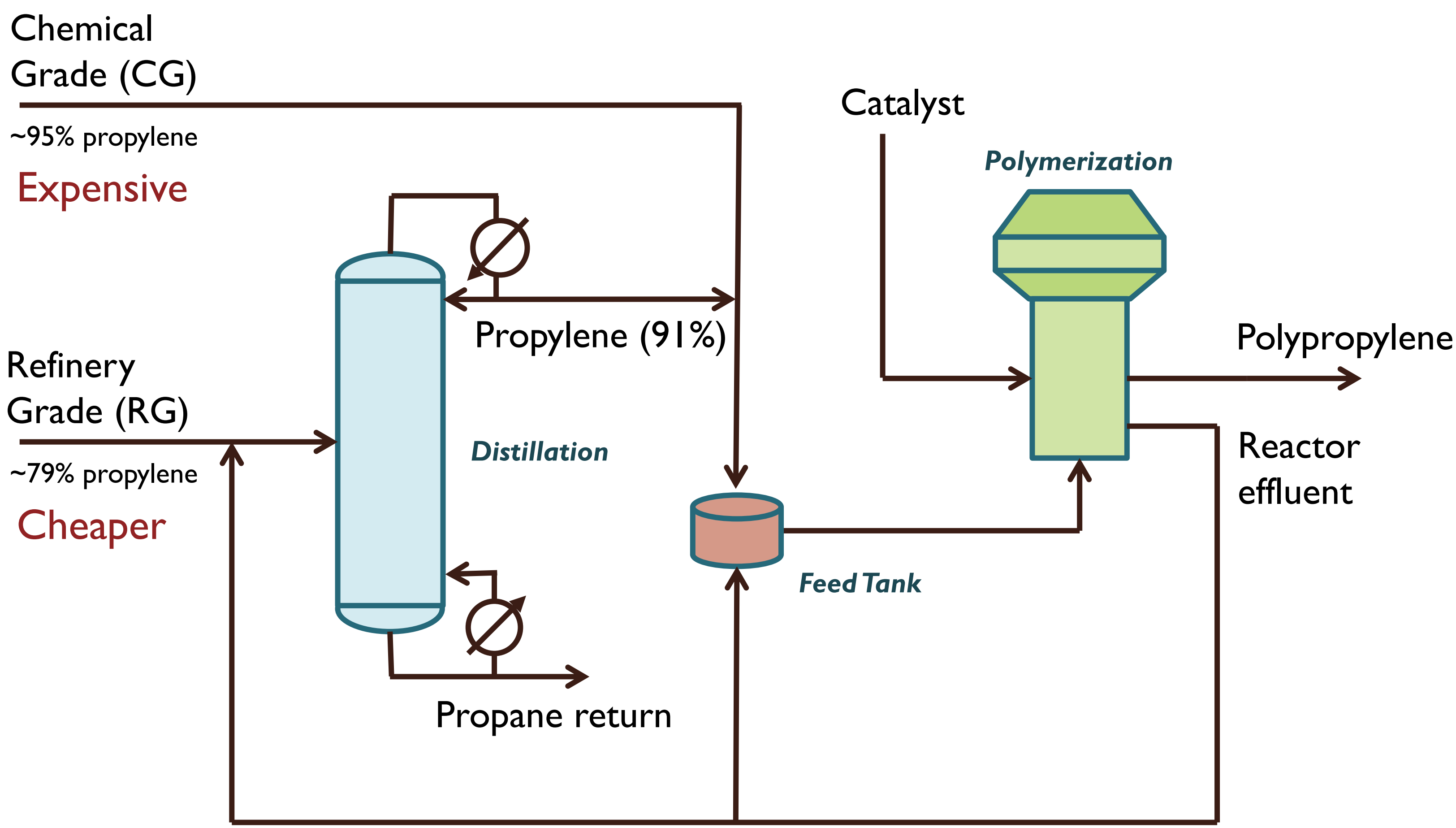

Goal: Select optimal mix of chemical and refinery grade propylene

Mathematical Model (***NLP***)

- Maximize Profit

- Constraints on each time interval:
  - Material balances
  - Min/Max flow rates
  - Constraints on composition of Propane Return, Distillation Overhead & Reactor Feed
  - Limits on catalyst yield and flow
  - Availability of Chemical Grade
  - Specifications on splitter feed and recycle rate

- Decision variables:
  - Production rate of polypropylene
  - RG and CG feedrates
  - Distillation overhead flow and composition
  - Reactor feed and catalyst flow

Single/Multiple Product Models

Single/Multiple Product Models

- Single Product Model (one time interval)
  - Maximize profit in terms of $/hr
  - Best production rate with minimum cost of feedstocks.
      - Model size: 149 variables, 146 constraints
      - Solved with CONOPT and BARON in less than 1 CPU s.

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- Multiple Product Model
  - Multiple orders of different products
  - Production sequence given beforehand
  - Profit (\$) = selling prices – feedstock costs
    + propane return – others
  - Solution gives best production rates with minimum costs for each product
  - Products of the same family feature same kinetic properties.
  - Aggregation/disaggregation allows to handle large scale test cases.

Models implemented with GAMS

Distillation Model

Objective:

- **Approximate procedure that provides overall treatment of the distillation** (no details about flows, composition, temperatures, etc. for each individual tray)
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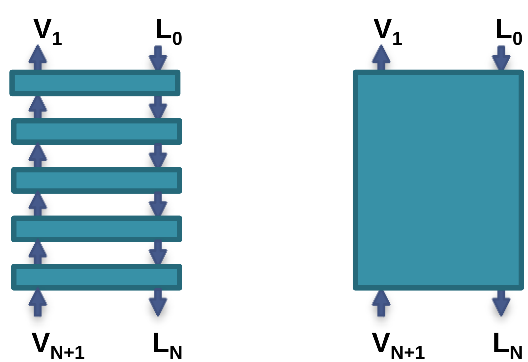
Aggregated group-method of Kamath et al. (2010)



Tray-by-Tray Method (Rigorous)

Group-Method (Approximate)

Kamath, Grossmann and Biegler (2010)
Comp. and Chem. Eng. 34, pp. 1312-1319

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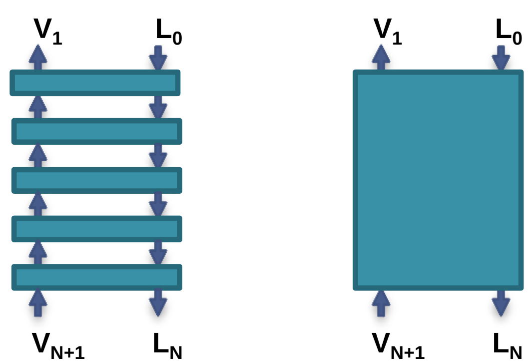

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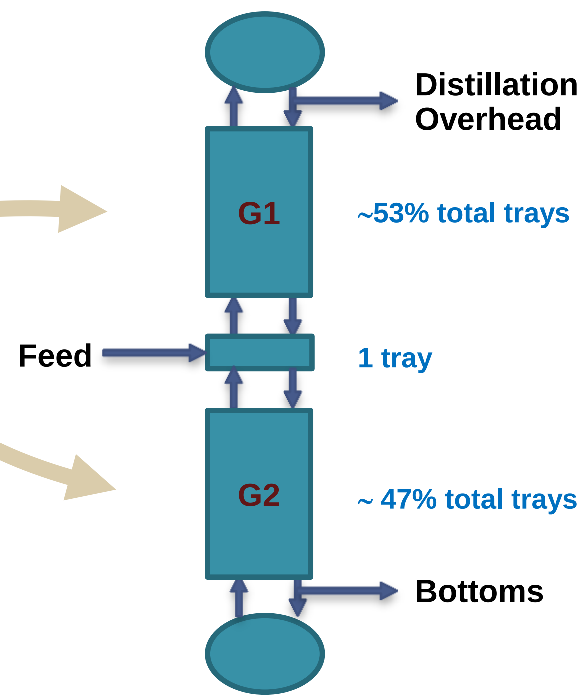
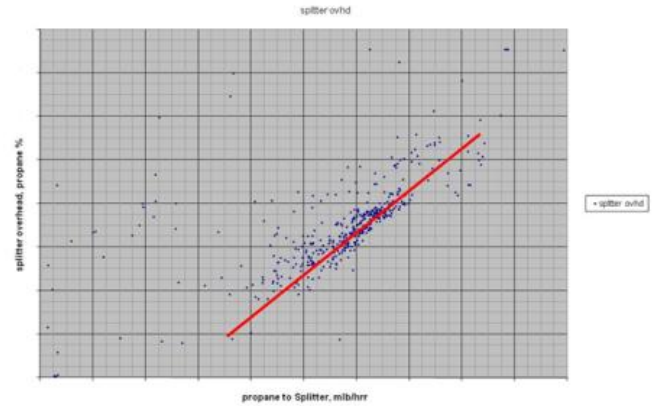
C3 Splitter modeled with Group-Method



Distillation Model

Parameterization and Validation

Initial linear correlation based on plant data



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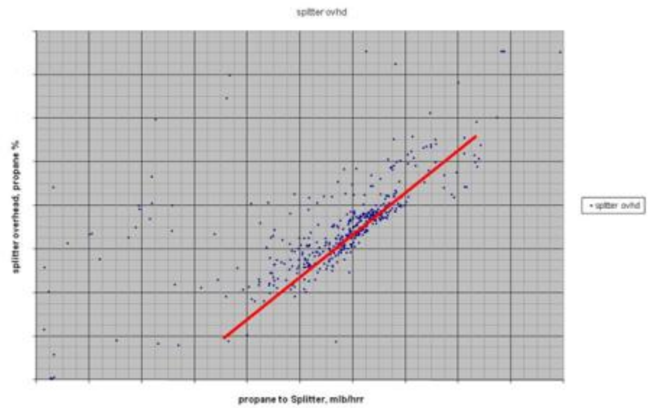

Degrees of freedom:
- **Reflux rate**
- **Bottoms composition**

<u>Additional Assumptions</u>
- **Fixed pressure for the whole column = 9.778 atm**
- **Total condenser (top)**
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- **Single feed**

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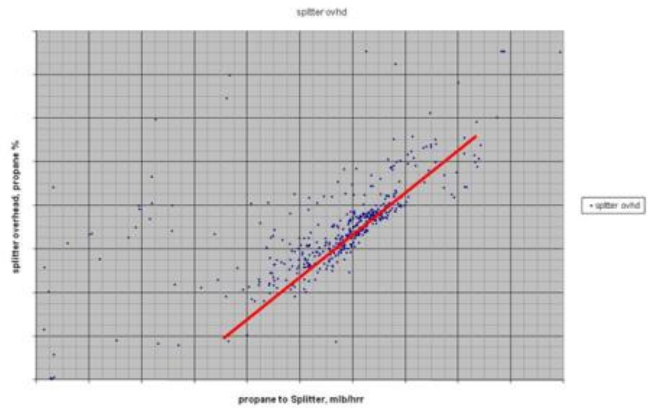

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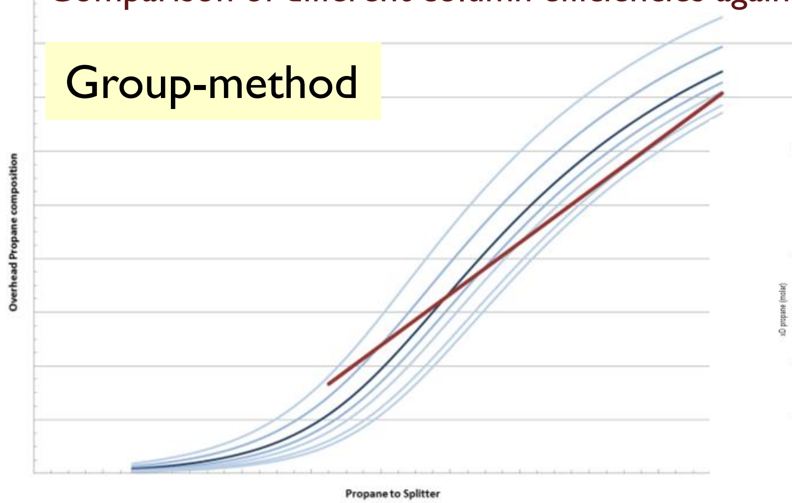
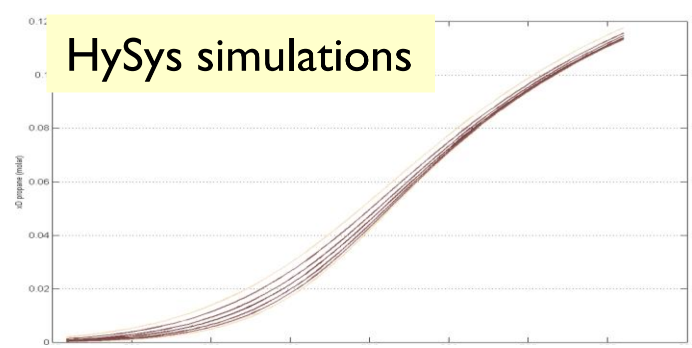
Comparison of different column efficiencies against rigorous tray-by-tray simulations (Aspen HySys)





Multiple Product Model

- Parameters
- Product and product family data
- Schedule

Aggregation / disaggregation procedure

- General results
- Detailed results

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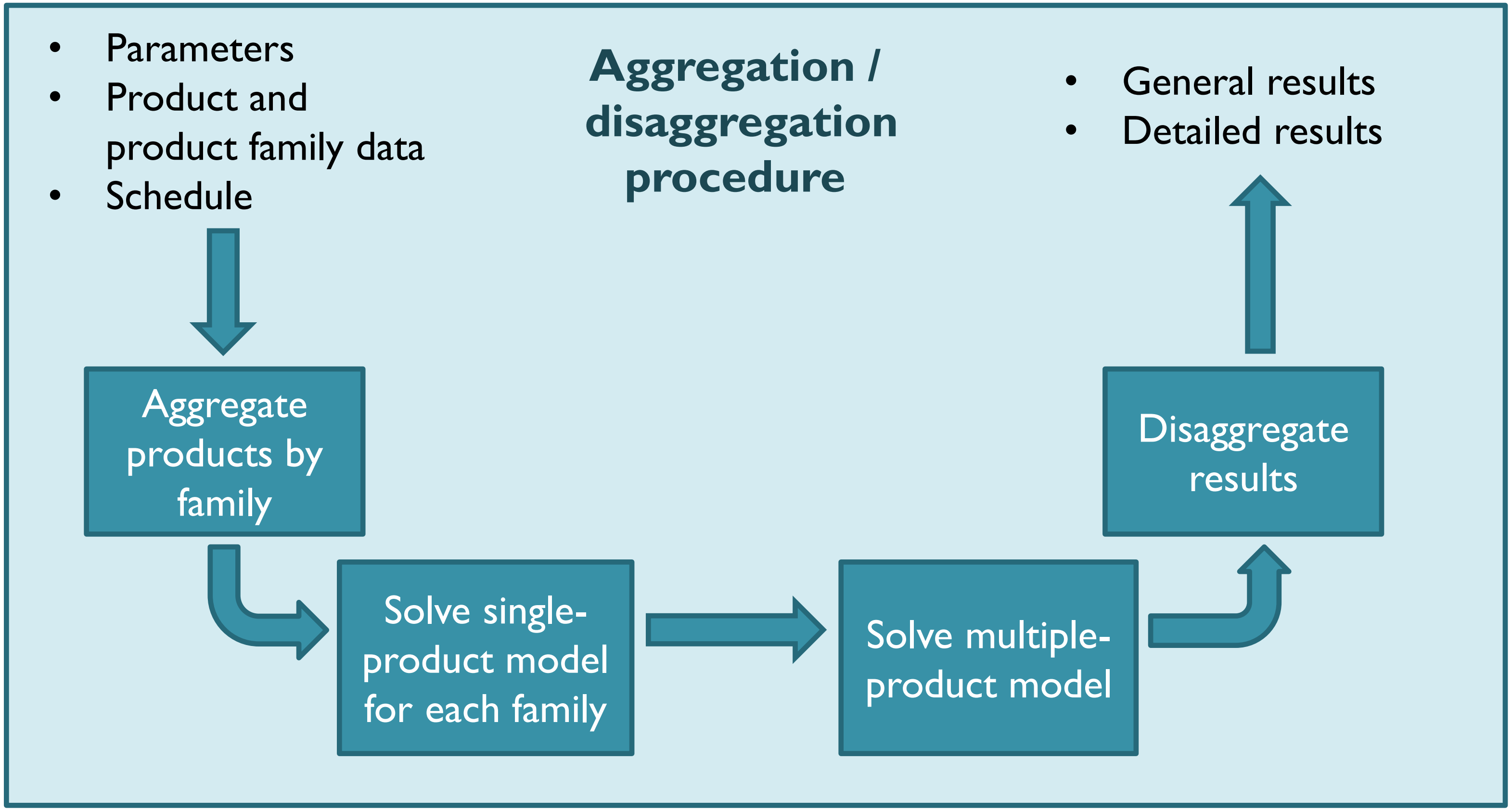

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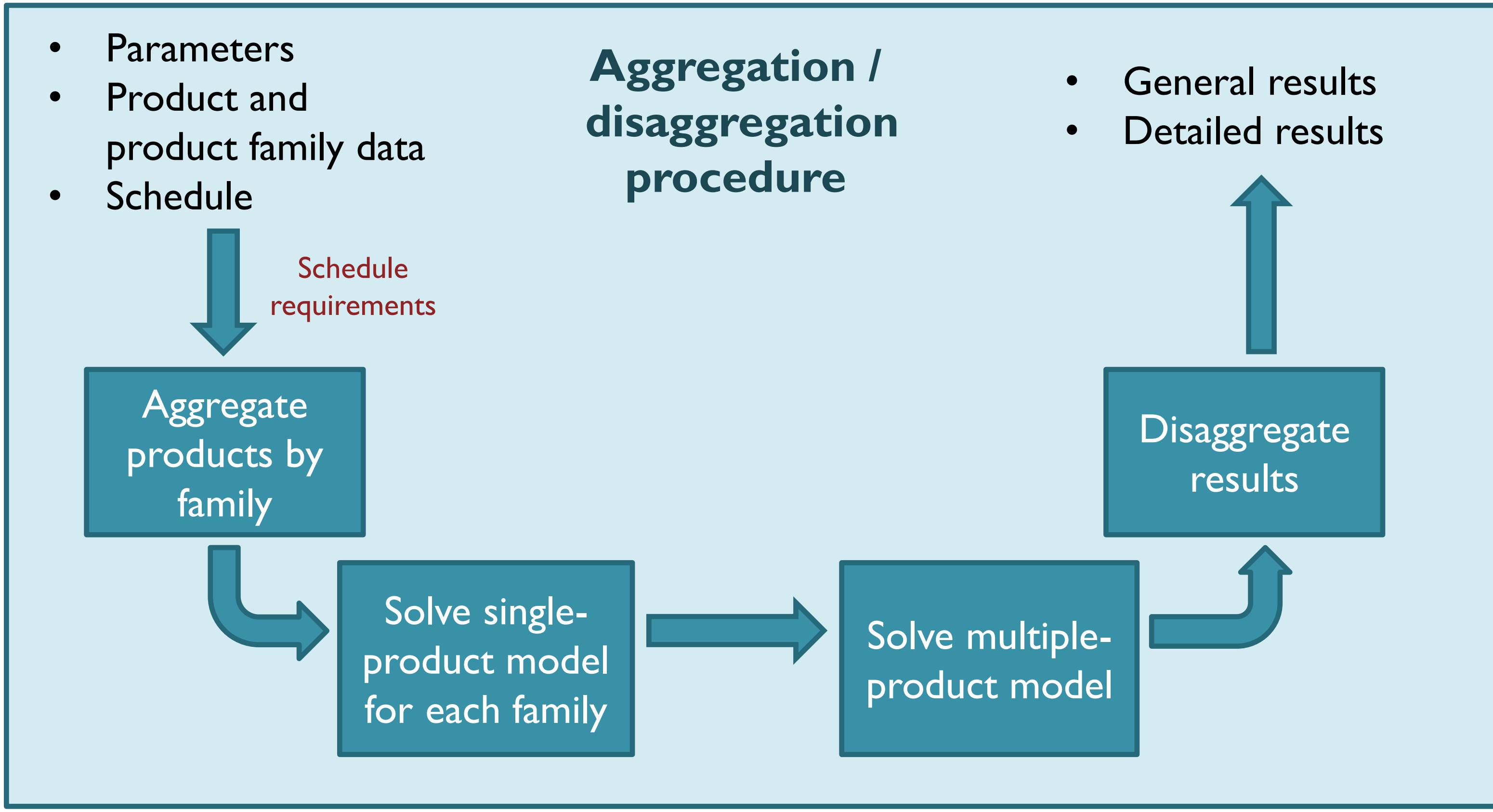

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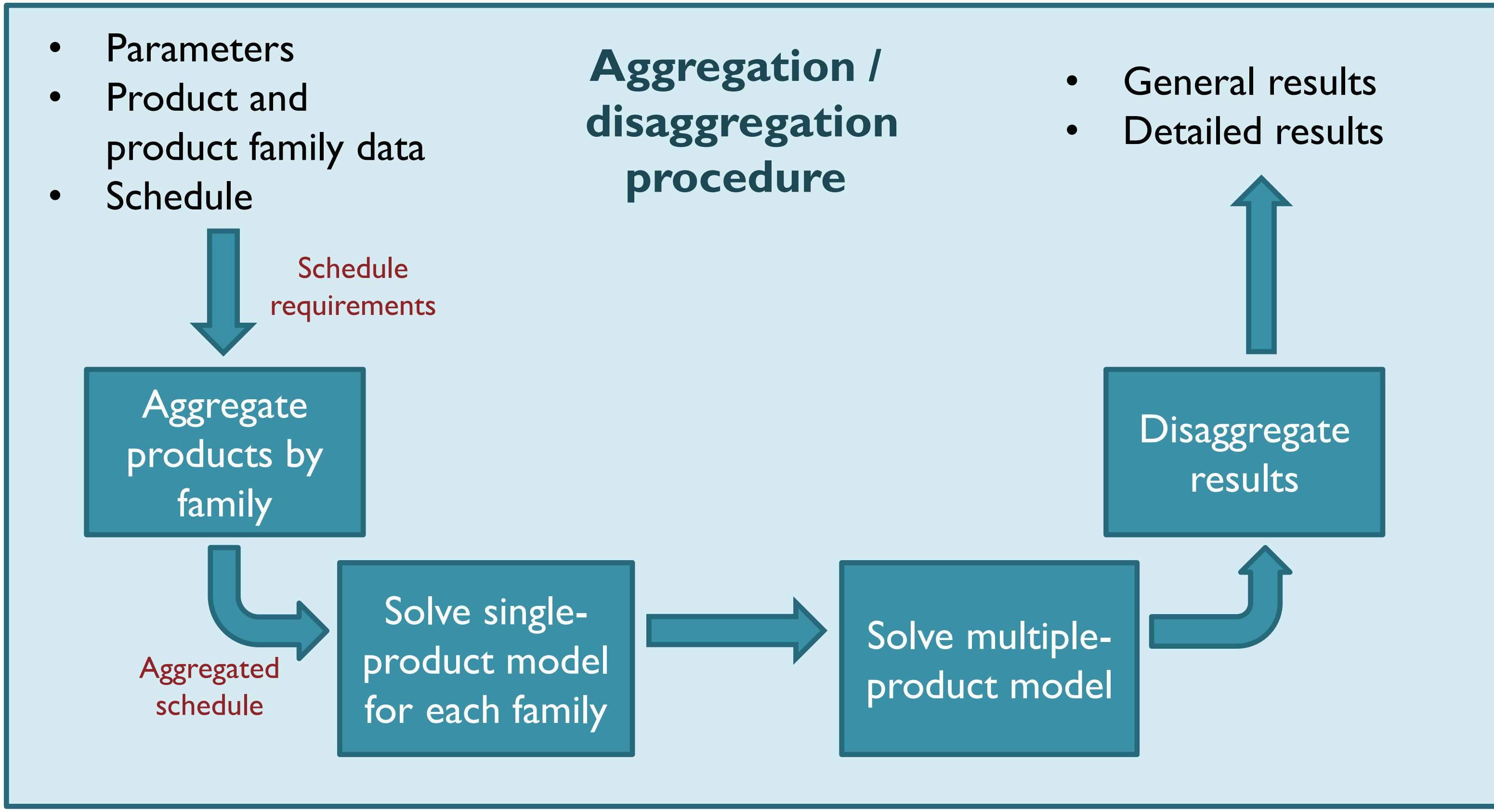

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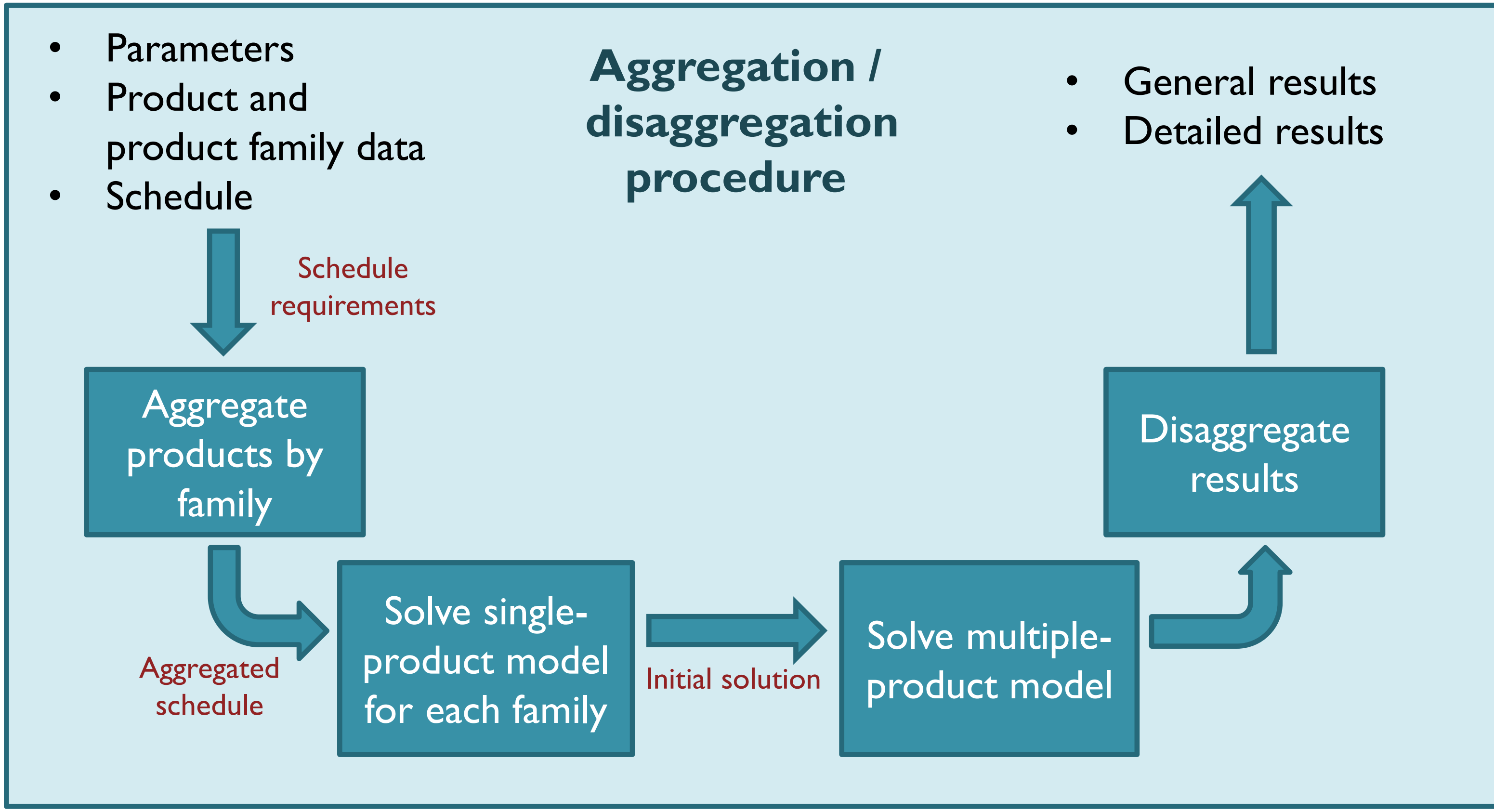

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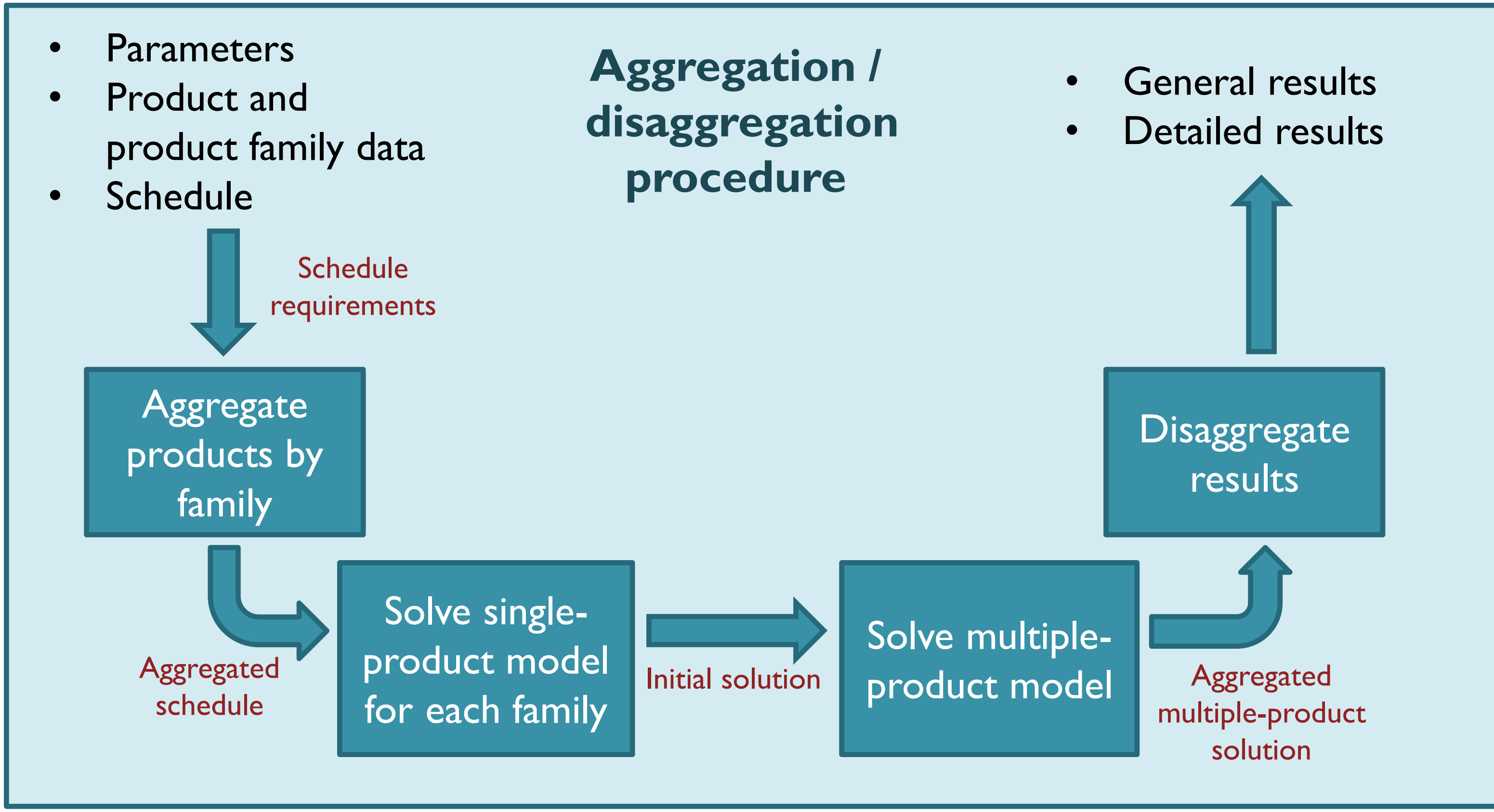

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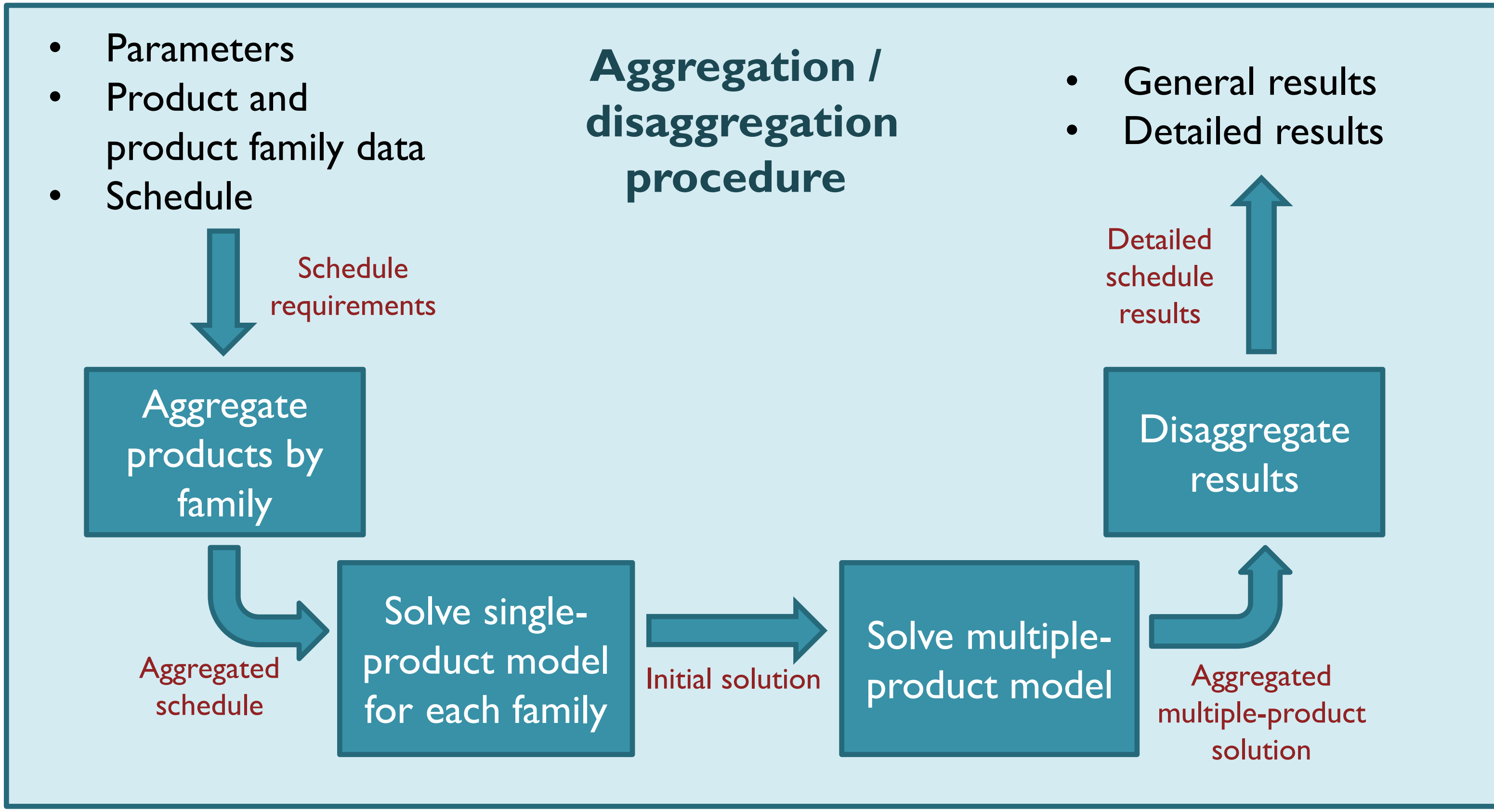

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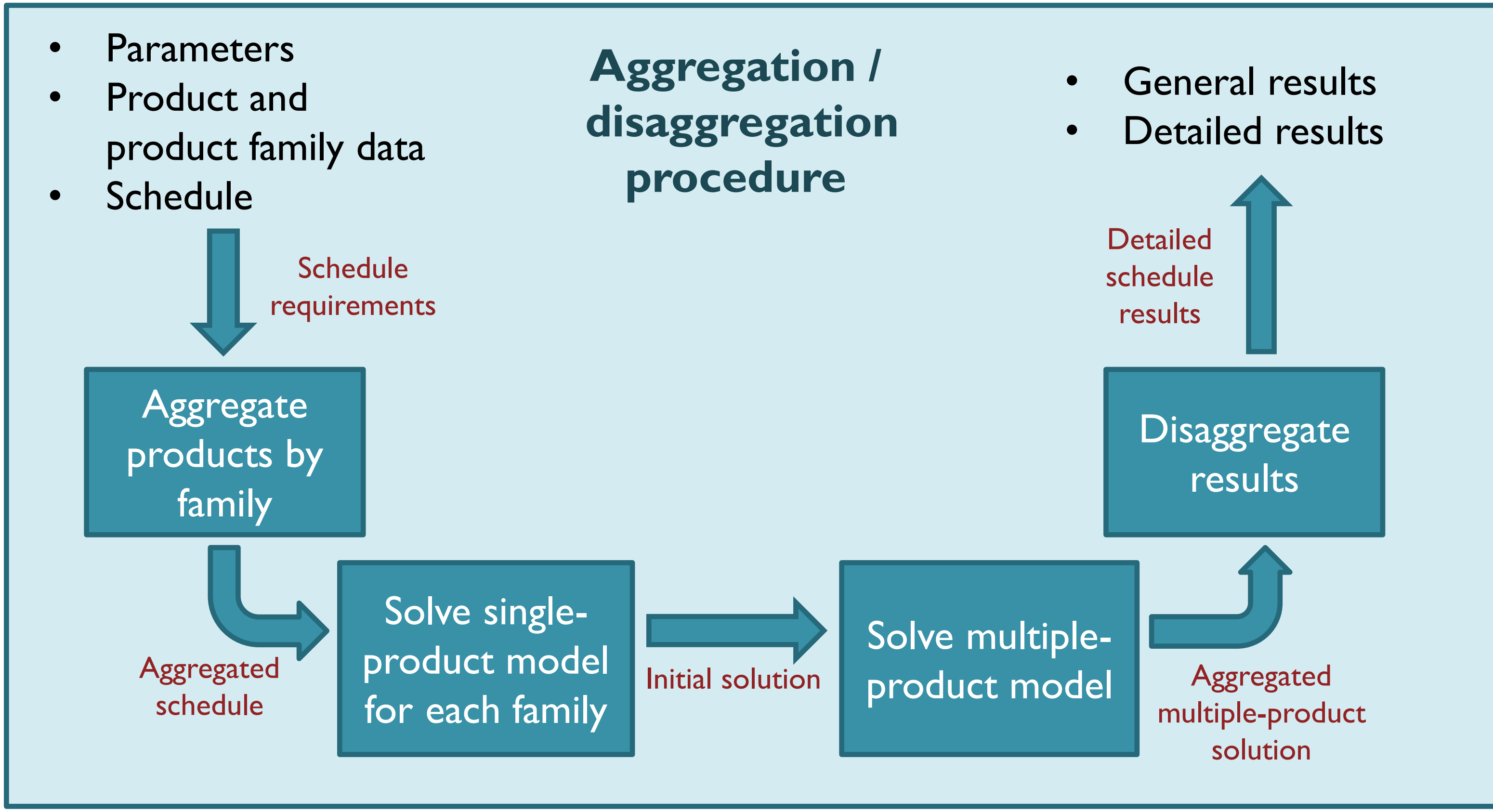

Mid-size example (20 products, 5 families)

- Model size: 750 variables, 736 constraints
- Solved by CONOPT in ~9 seconds.
- Preliminary results show **realistic tradeoff on feedstocks costs vs production rates** (depending on available time).

Multiple Product Model - Example

Different time horizons tested to measure the **tradeoff** of **feedstock costs** versus **production rates**.

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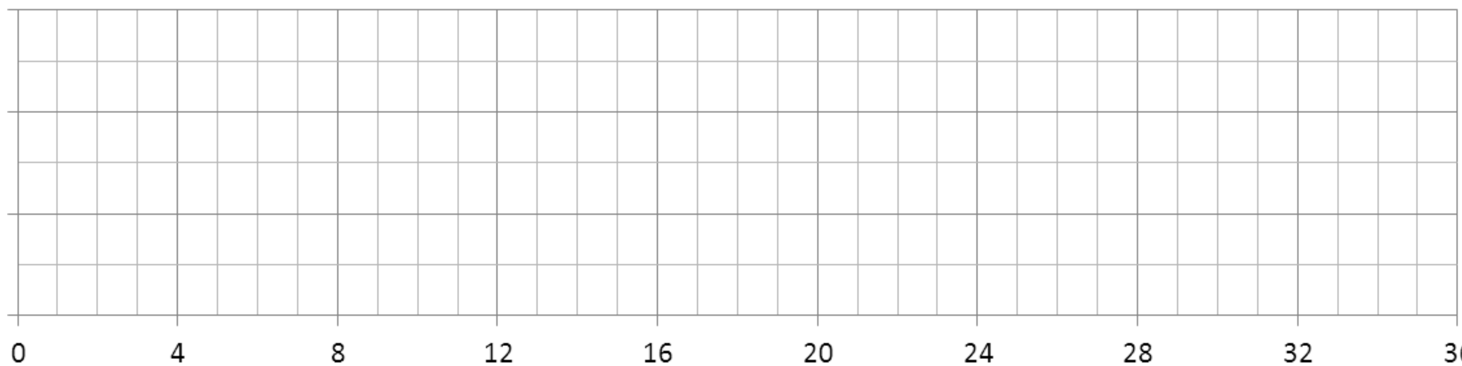

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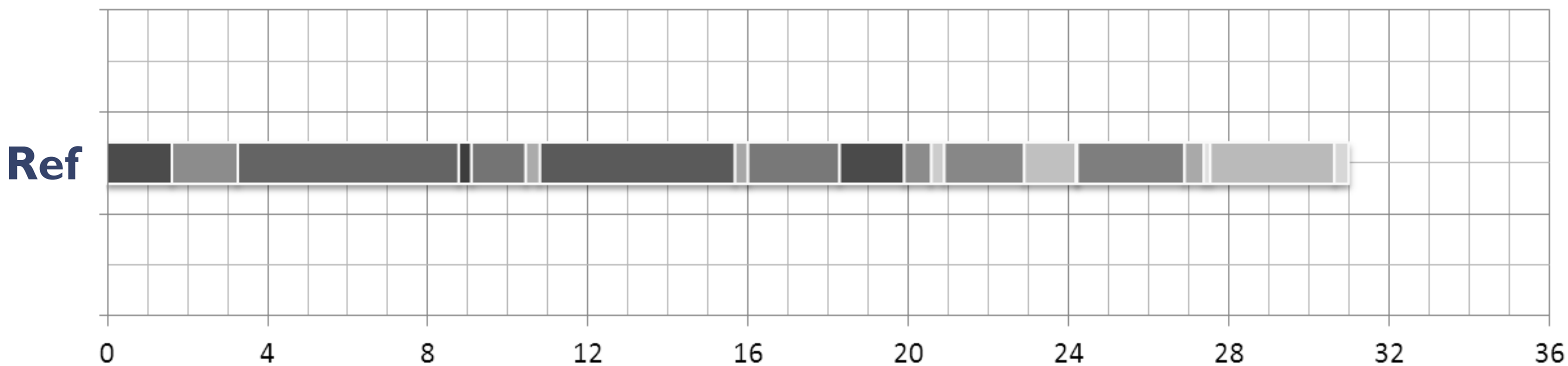

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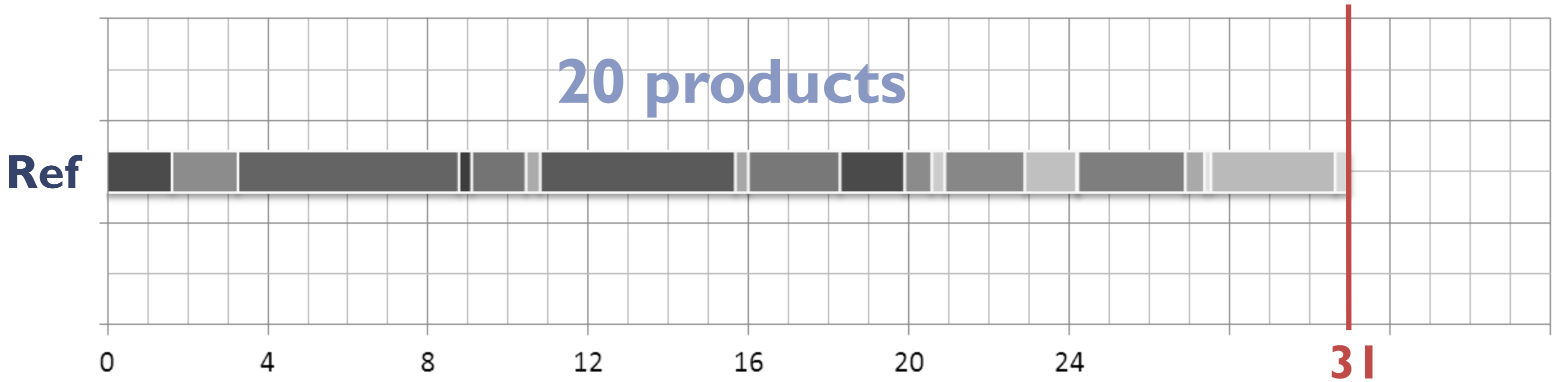

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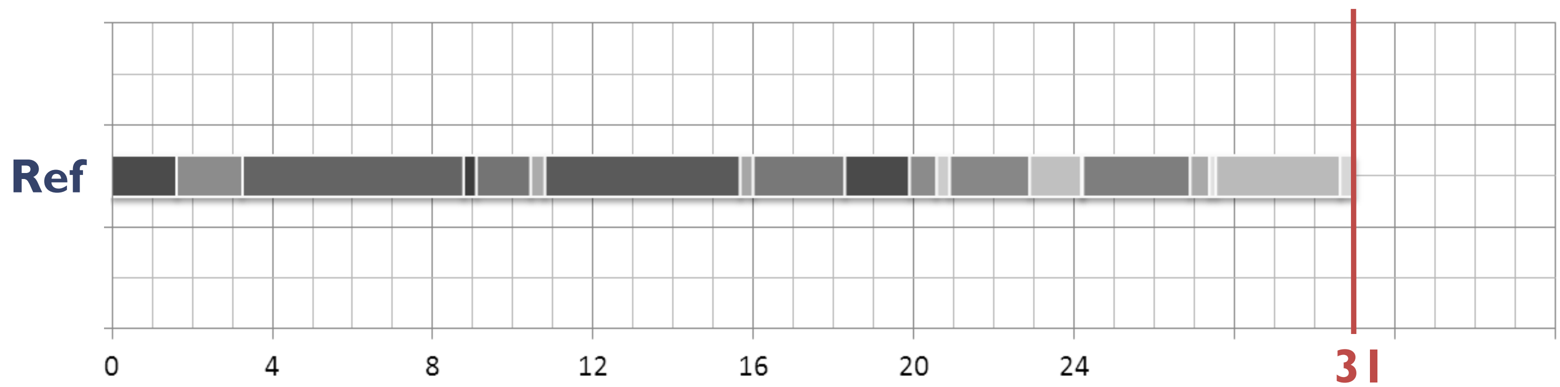

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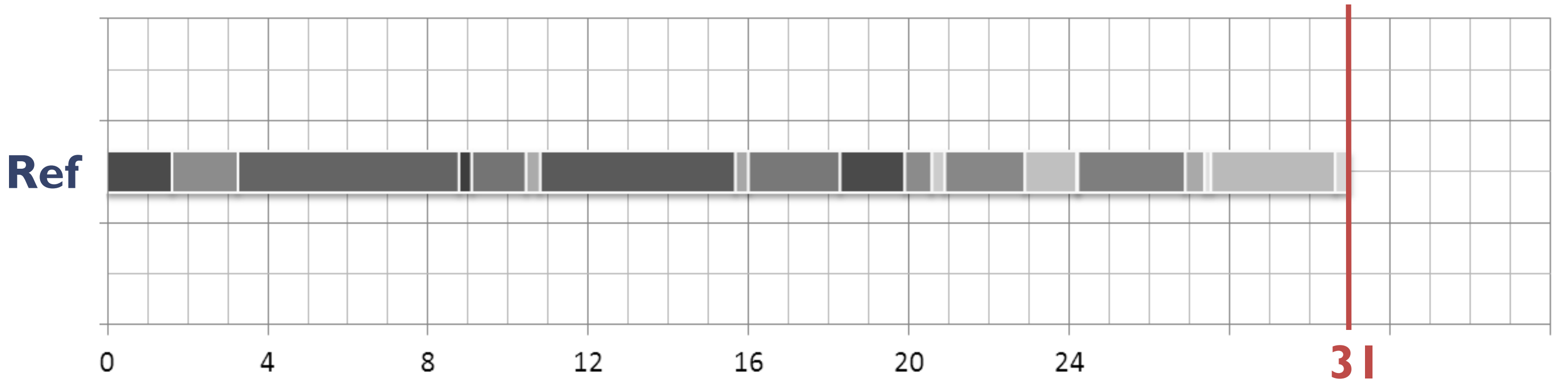

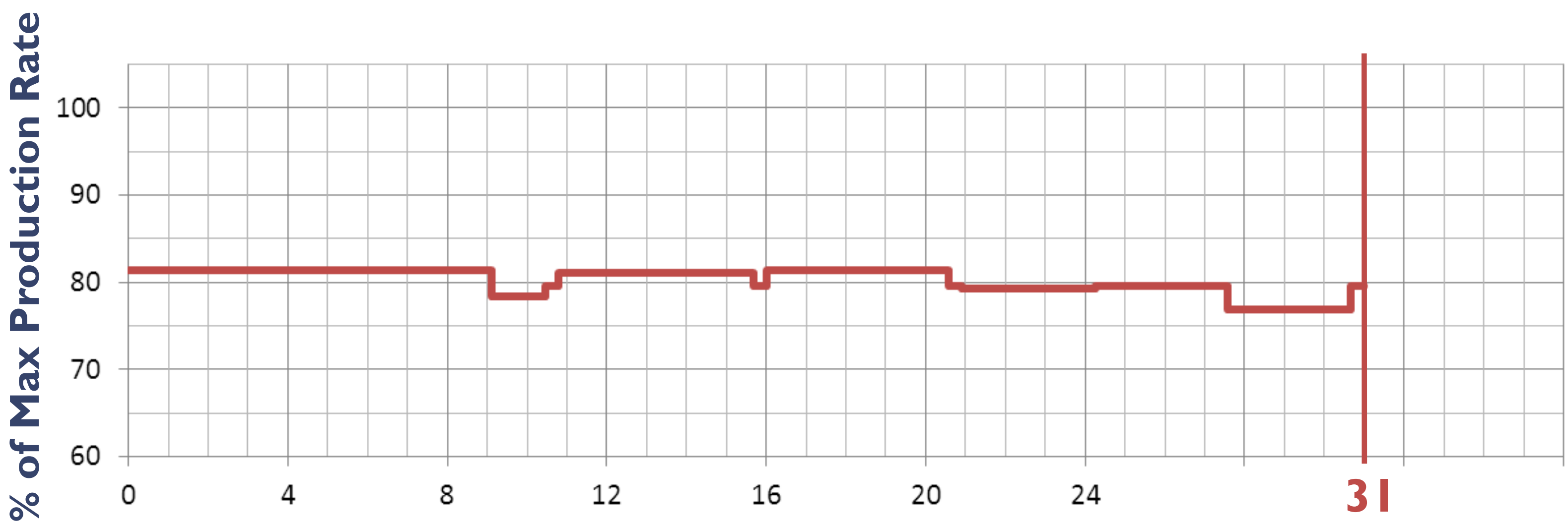

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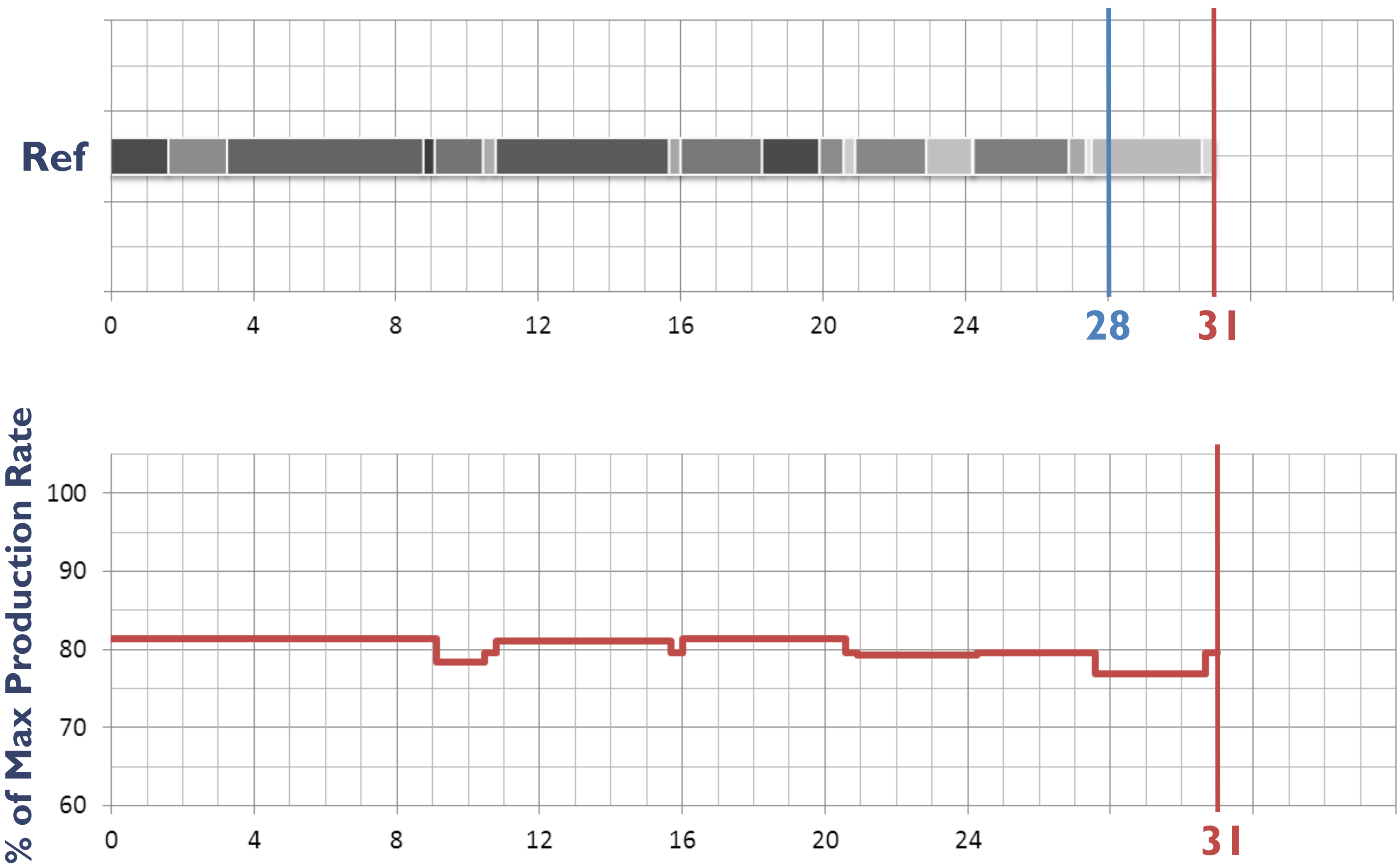

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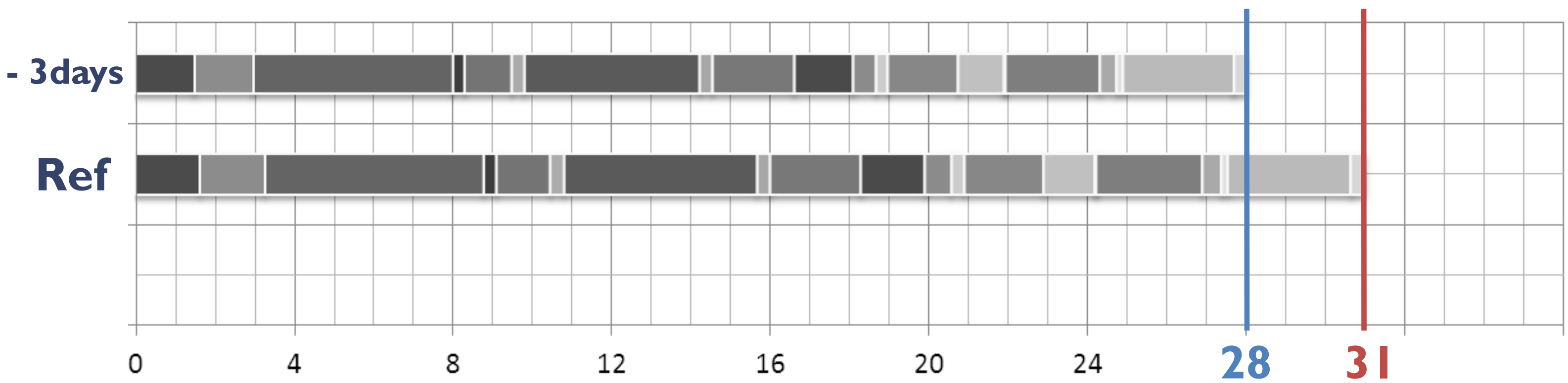

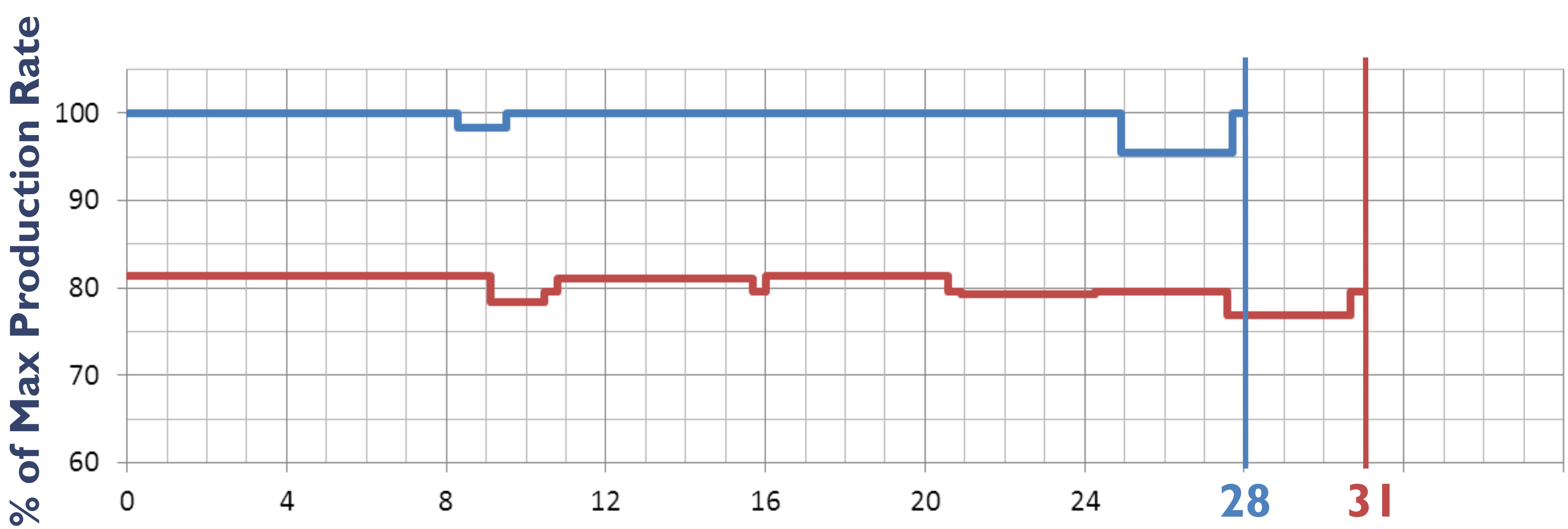

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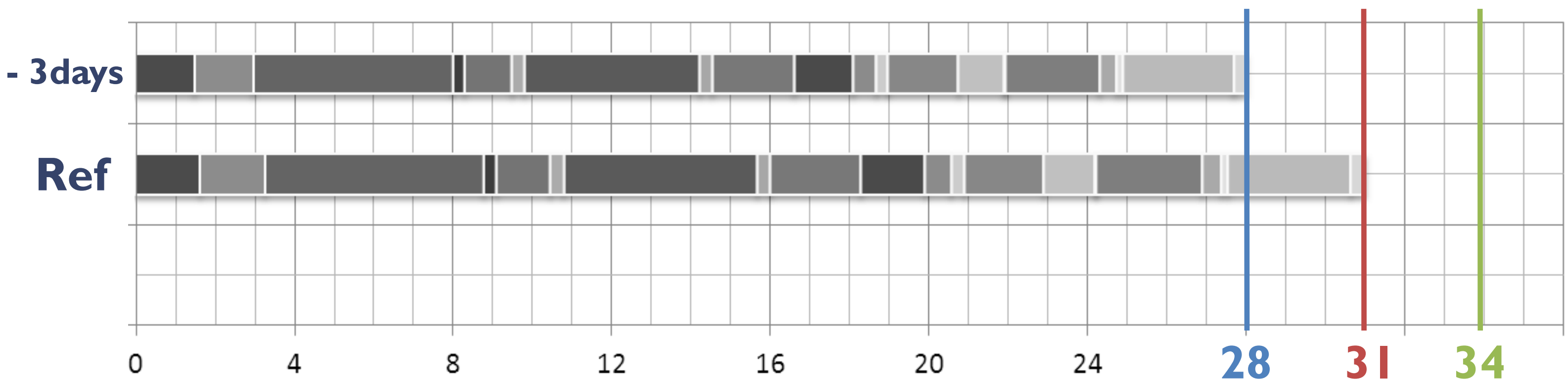

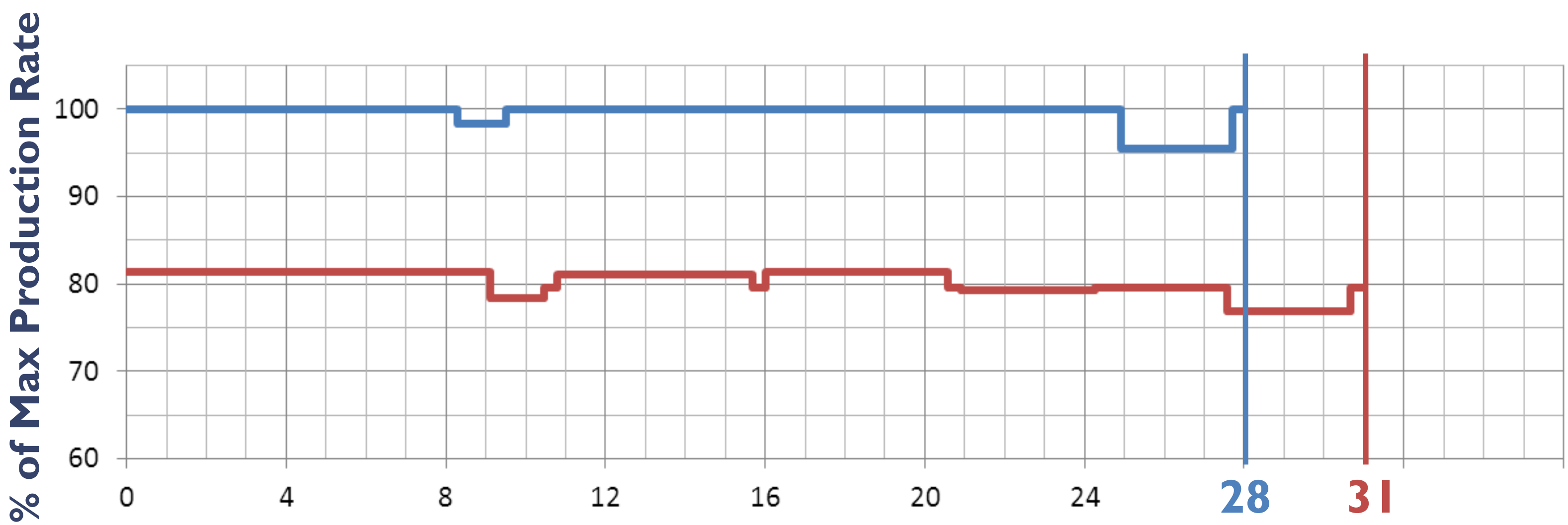

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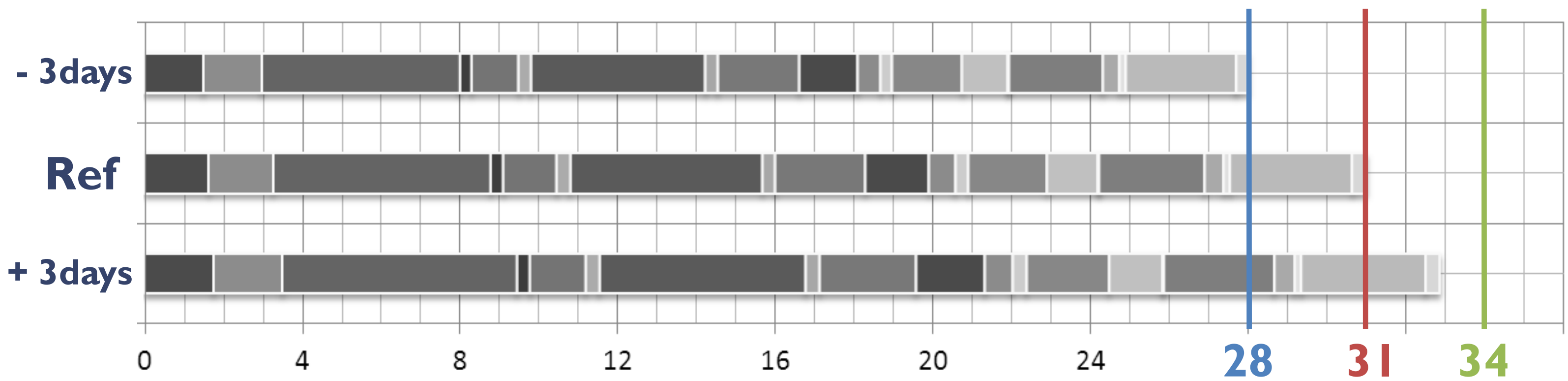

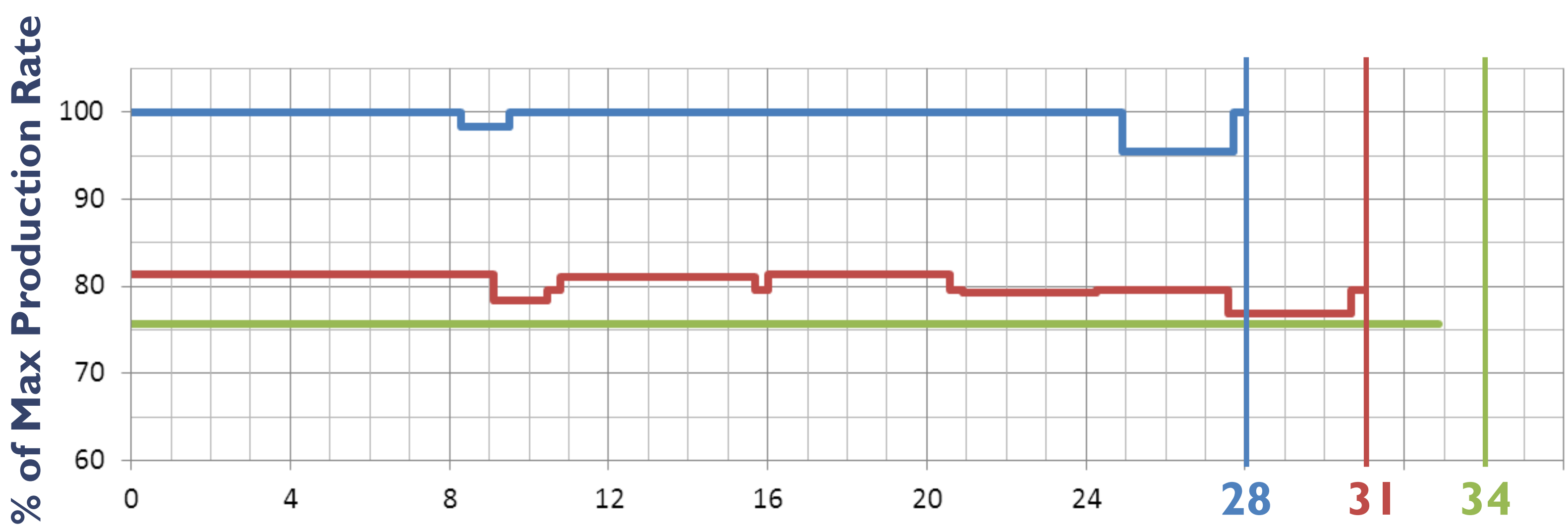

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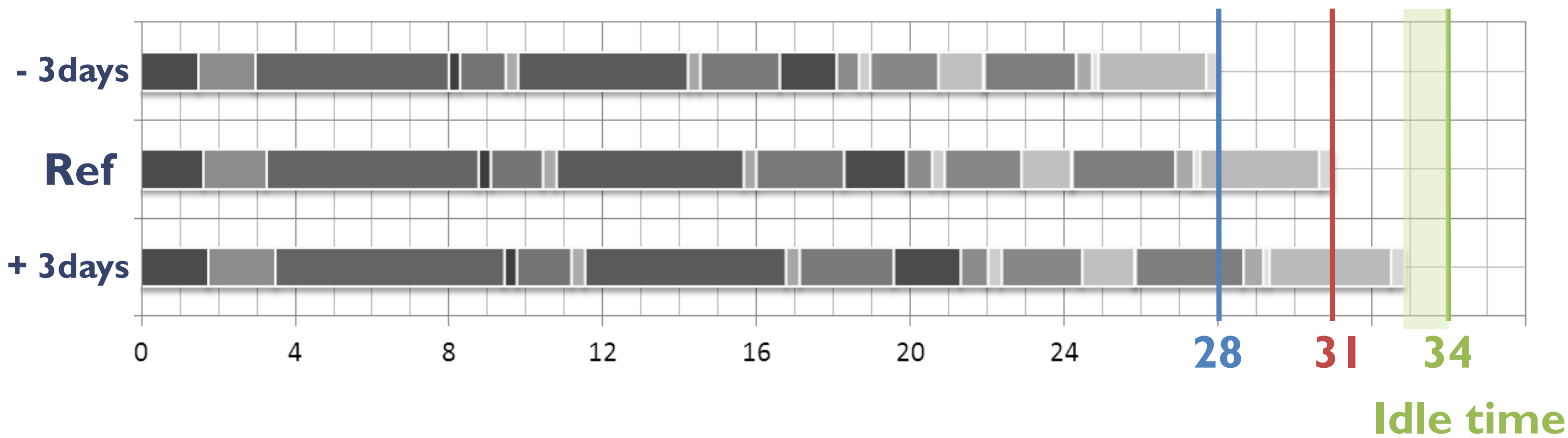

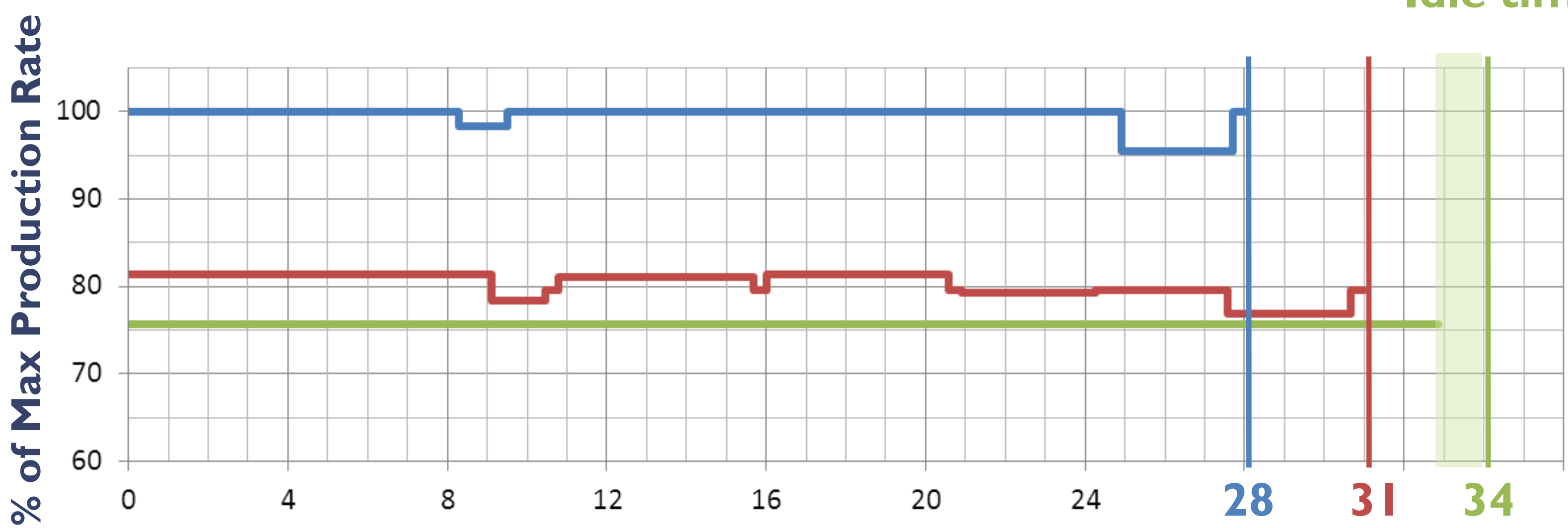

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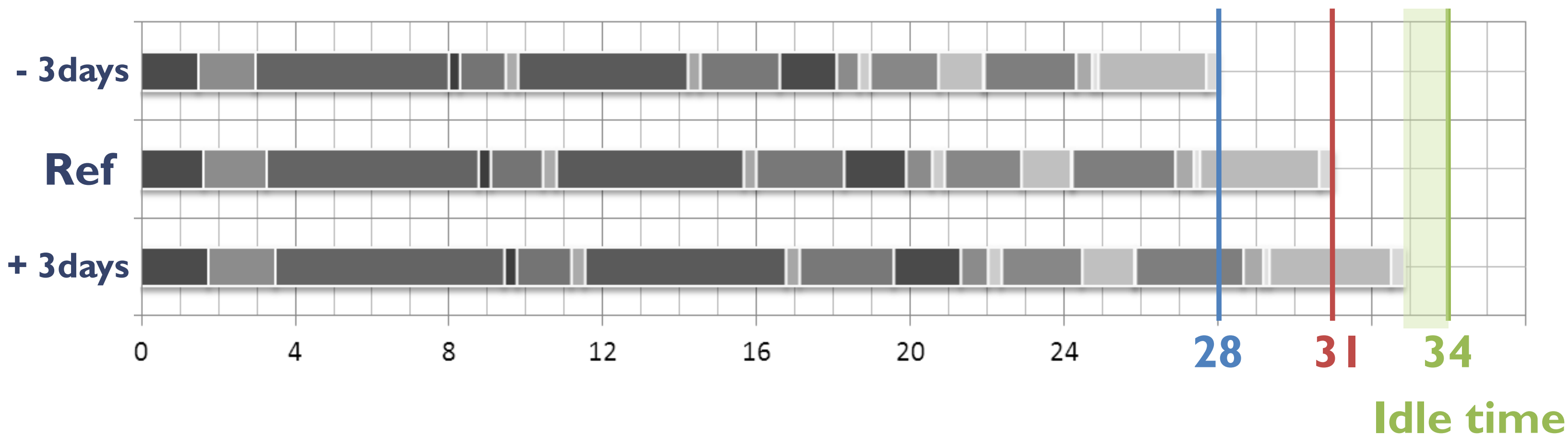
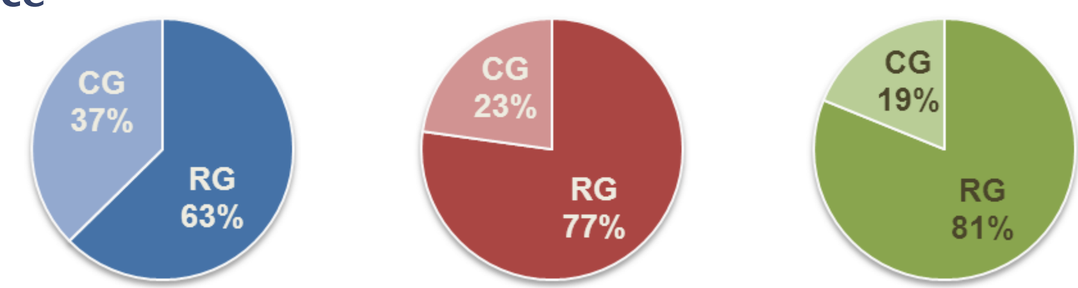


Propylene Source



Optimal Solution (PROFIT)

88.1 MU	**100.0** MU	**103.2** MU

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Added "slack" product to assess the benefits of extra production when schedule finishes early ➔ **gain/loss opportunity**

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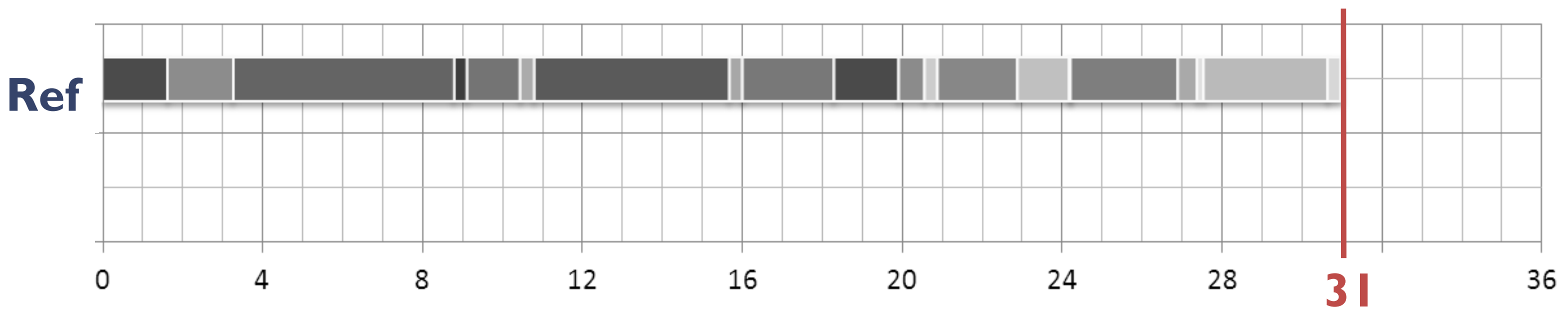

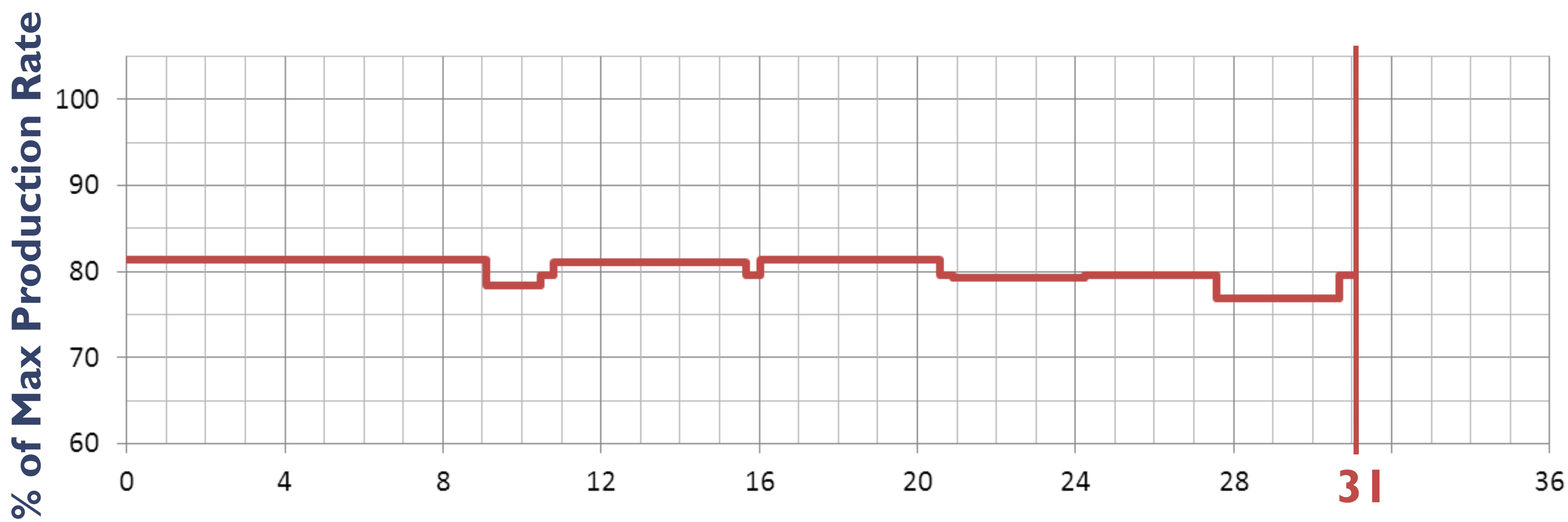

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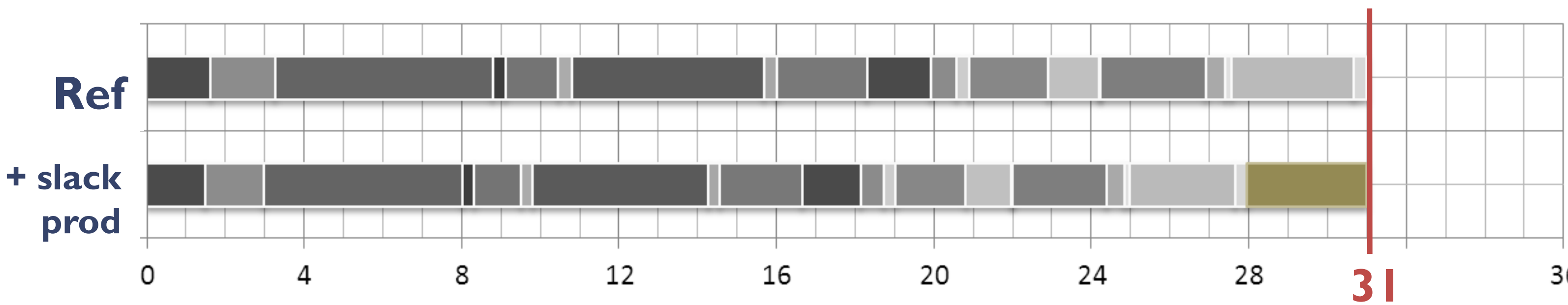

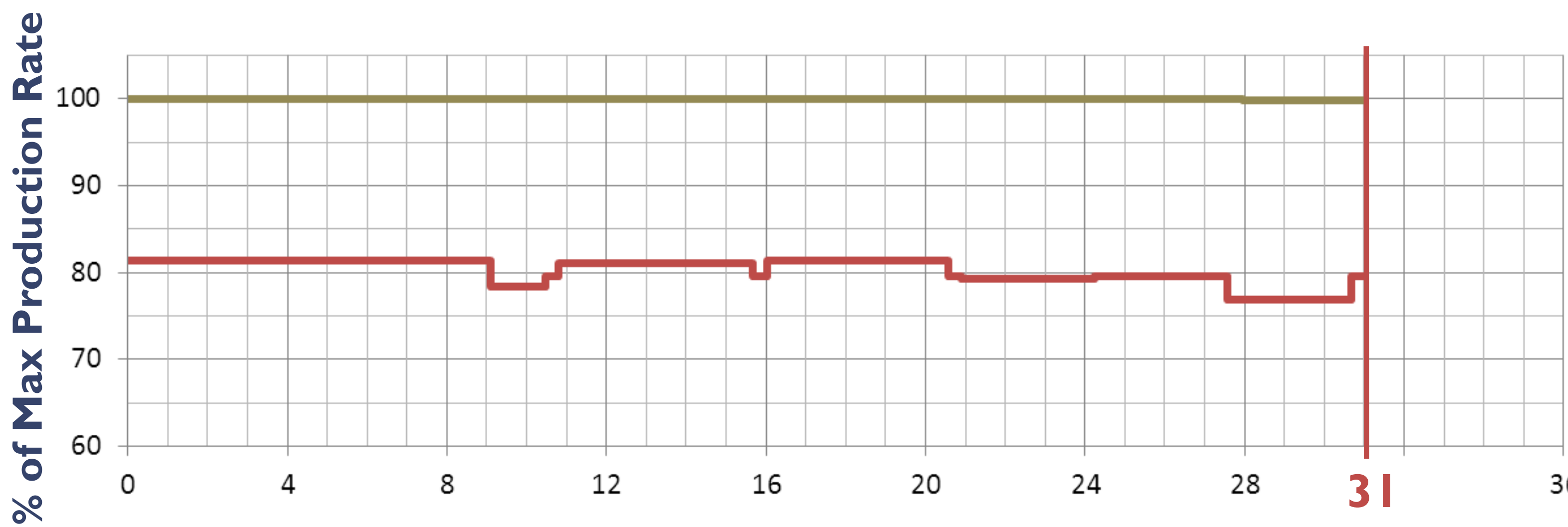

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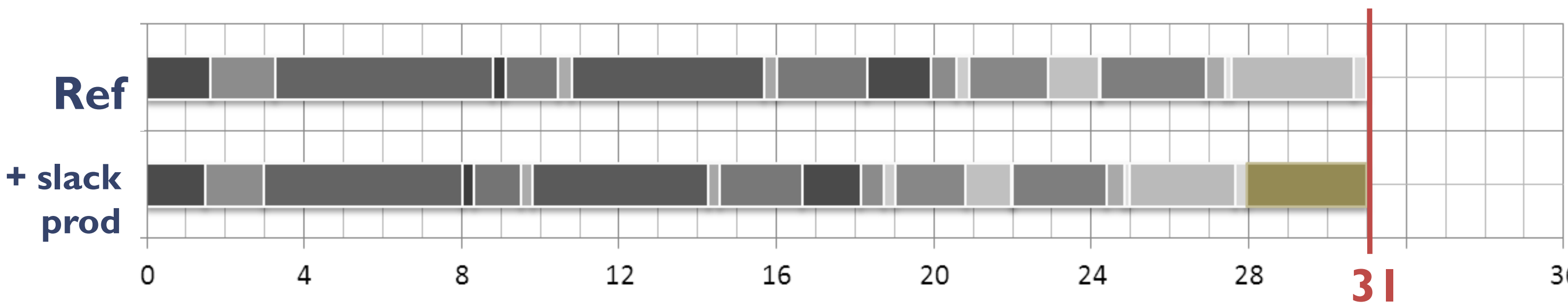

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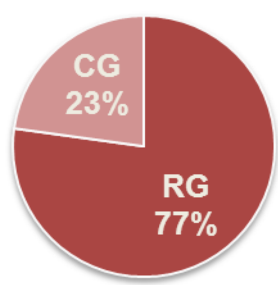

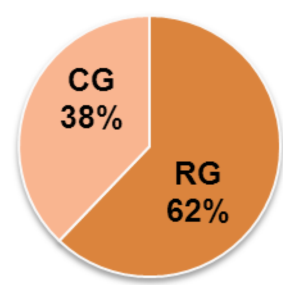

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User interface for GAMS multiple-product model developed in MS Excel

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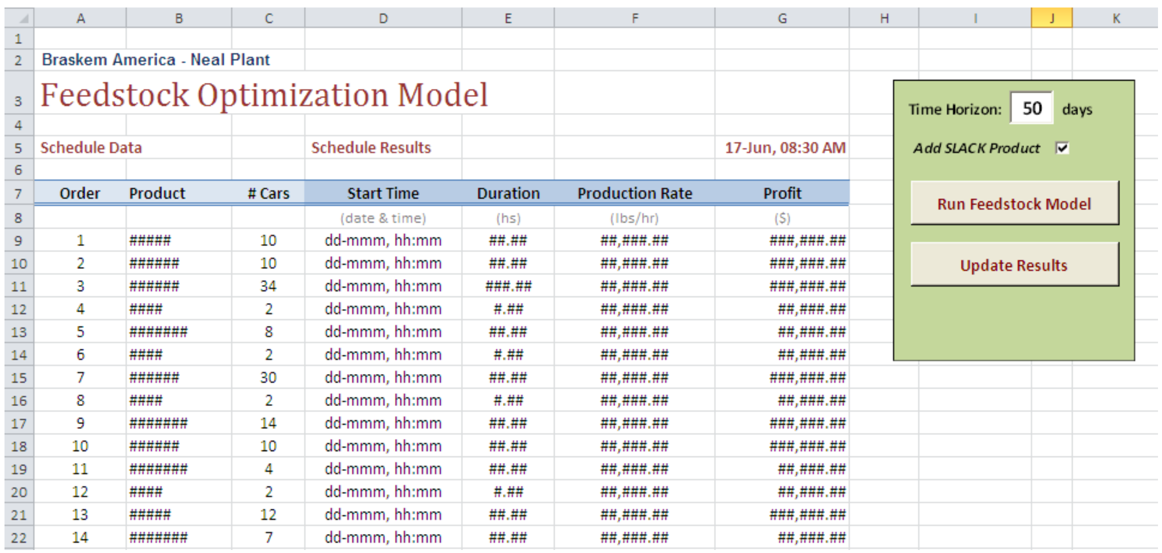

Braskem America - Neal Plant

Feedstock Optimization Model

Schedule Data | Schedule Results | 17-Jun, 08:30 AM

Order	Product	# Cars	Start Time	Duration	Production Rate	Profit
			(date & time)	(hs)	(lbs/hr)	($)
1	#####	10	dd-mmm, hh:mm	##.##	##,###.##	###,###.##
2	######	10	dd-mmm, hh:mm	##.##	##,###.##	###,###.##
3	######	34	dd-mmm, hh:mm	###.##	##,###.##	###,###.##
4	####	2	dd-mmm, hh:mm	#.##	##,###.##	##,###.##
5	#######	8	dd-mmm, hh:mm	##.##	##,###.##	##,###.##
6	####	2	dd-mmm, hh:mm	#.##	##,###.##	##,###.##
7	######	30	dd-mmm, hh:mm	##.##	##,###.##	###,###.##
8	####	2	dd-mmm, hh:mm	#.##	##,###.##	##,###.##
9	#######	14	dd-mmm, hh:mm	##.##	##,###.##	###,###.##
10	######	10	dd-mmm, hh:mm	##.##	##,###.##	###,###.##
11	#######	4	dd-mmm, hh:mm	##.##	##,###.##	##,###.##
12	####	2	dd-mmm, hh:mm	#.##	##,###.##	##,###.##
13	#####	12	dd-mmm, hh:mm	##.##	##,###.##	###,###.##
14	#######	7	dd-mmm, hh:mm	##.##	##,###.##	##,###.##

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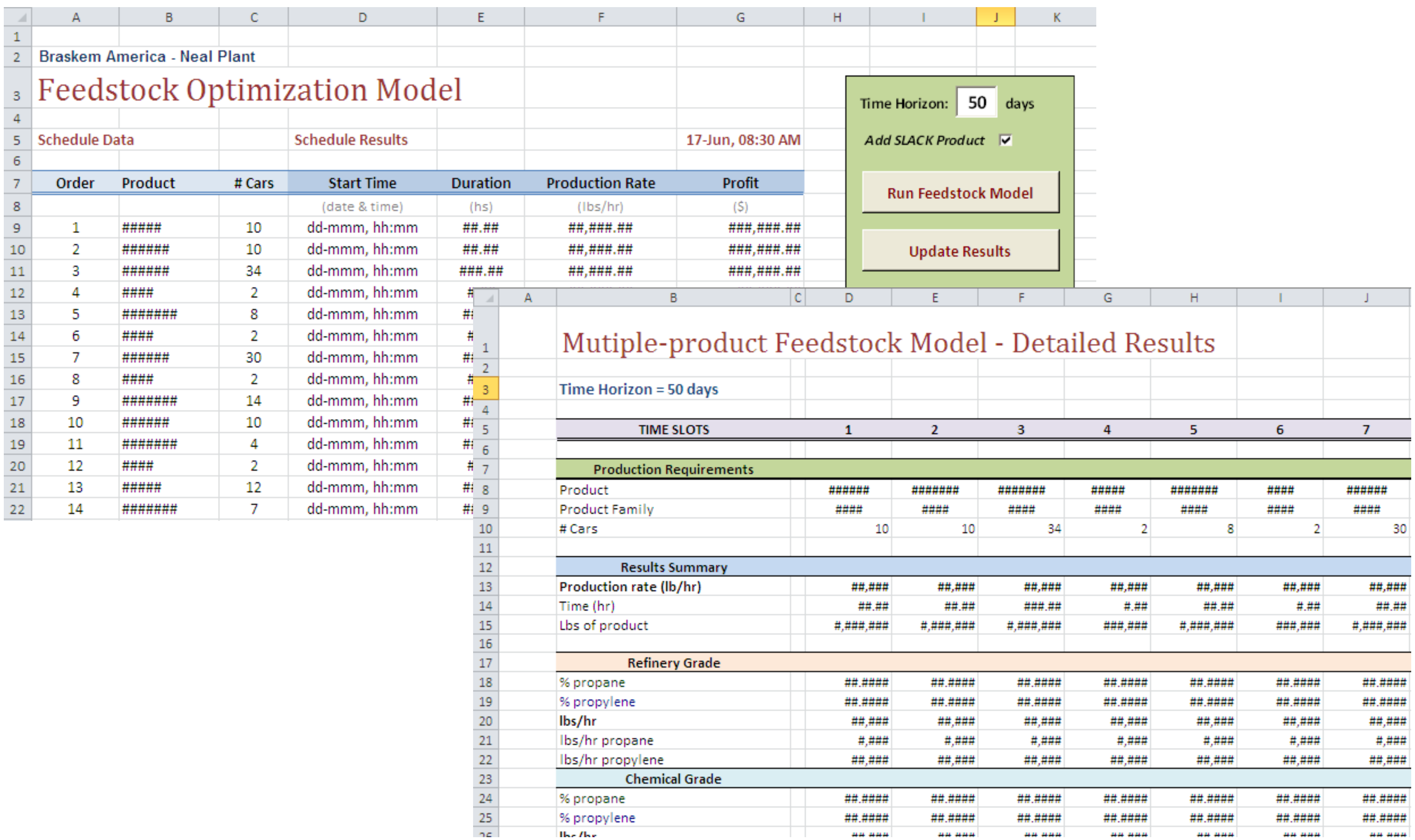

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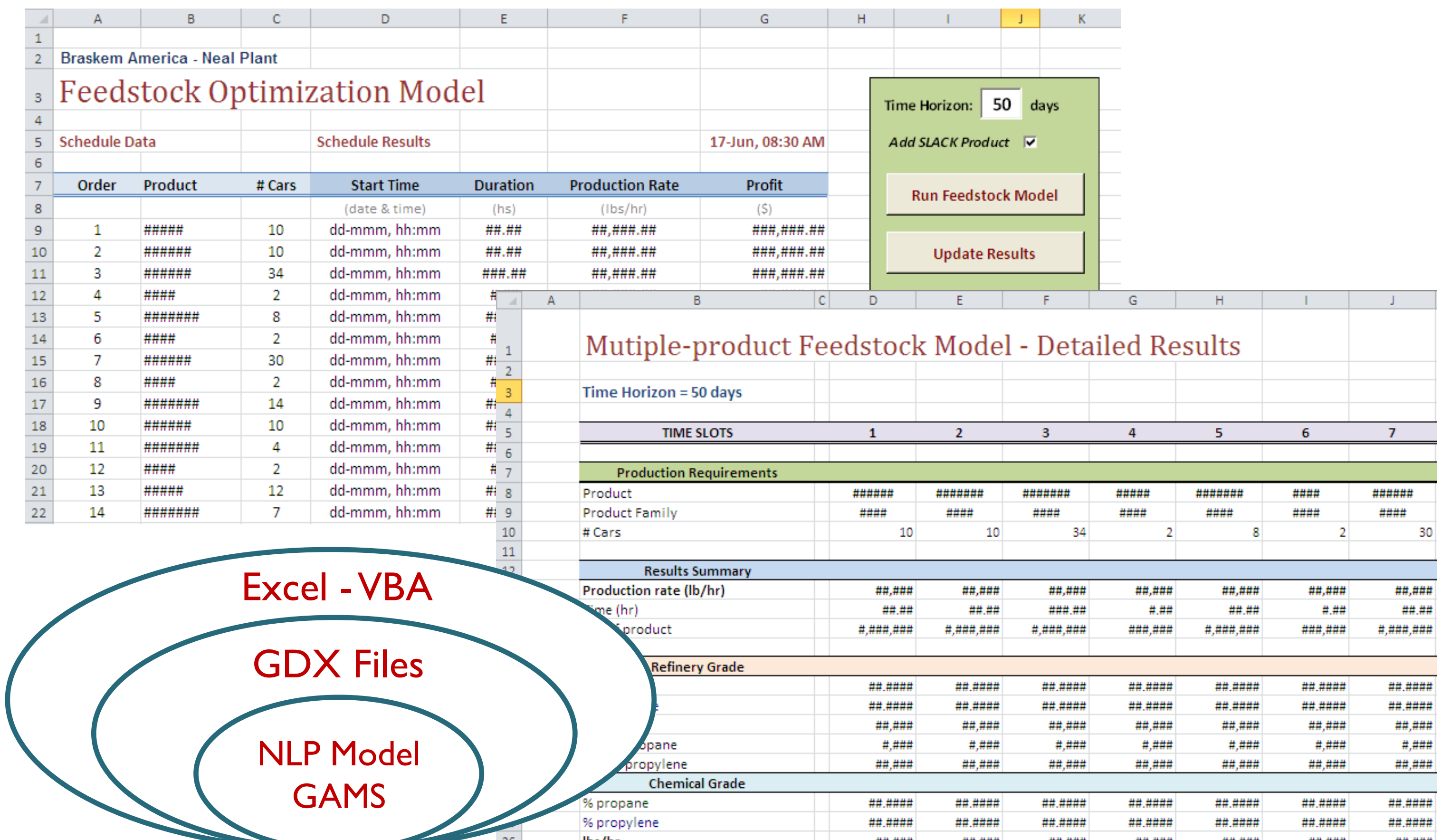

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- Proposed method handles gain/loss scenarios and large schedules (through aggregation/disaggregation).
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FUTURE WORK

- Improvements on distillation model parameters.

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Thanks for your attention!
Questions?