Planning of a Network of Batch Plants with Blending

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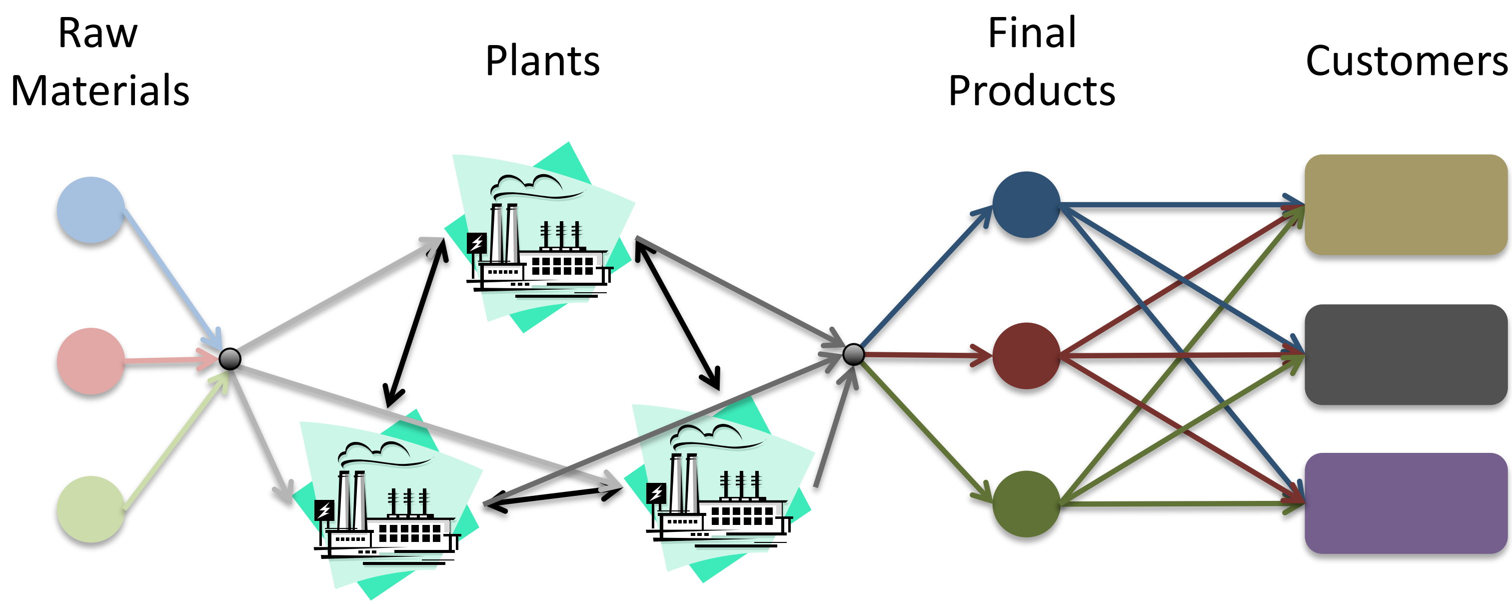
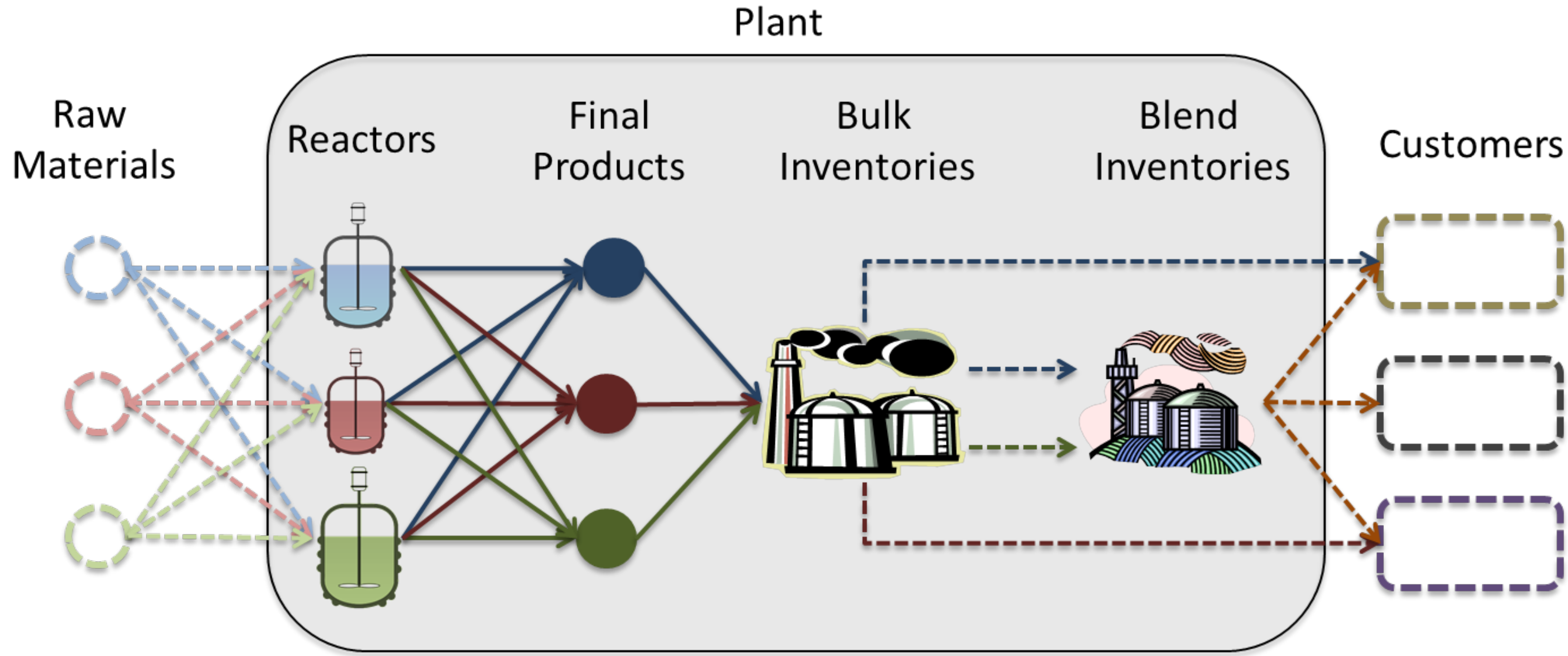
Motivation



- Long-term planning does not include batch transitions (changeovers) and capacity losses due to that
- Transition losses can impact implementation of the production plan
- Simultaneous production planning with batch sequencing

Network Characteristics



- Intermediates may be shipped between plants
- A subset of products are blended, with blending ratios specified
- Finished products are sourced to customers by at most one plant
- Scale-up costs associated with the introduction of products to plants that do not normally produce them and their batches are subject to testing

Problem Statement

- **Given**
  - Number of products to be produced (subset by blending)
  - Batch sizes and fixed processing times
  - Maximum campaign length for each product in each time period
  - Production, transportation, and scale-up costs
  - Sequence-dependent changeover times between groups of products
  - Demand forecast over a time horizon
- **Determine**
  - Production volumes for each product in each unit
  - Demand of a customer is fulfilled by which plant
  - Sequencing of groups in each unit of each plant and time period
  - Inter-plant shipments and inventory stored
- **Objective Function**
  - Minimize: Total Cost
    - Operating, Transportation, Scale-up costs, Inventory penalties

Model Characteristics

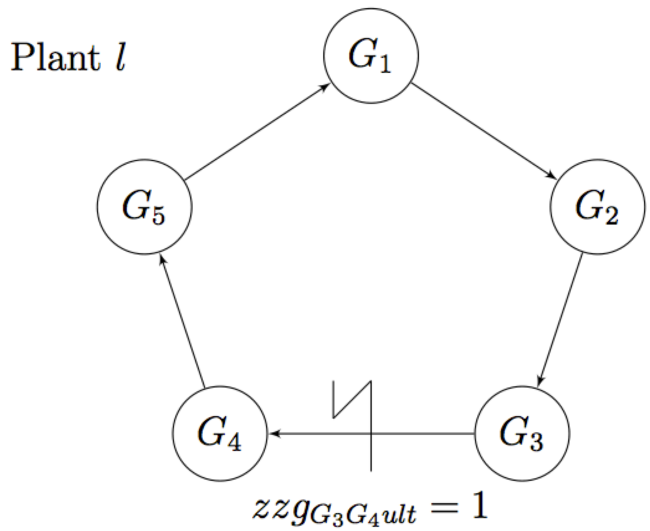
- Mixed-Integer Linear Programming (MILP) model
- Single-period planning model with a multi-period batch sequencing considerations
- Constraints
  - Allocation of Products to Plants
  - Sequencing of Groups of Products
  - Time Horizon
  - Material and Inventory Balances
    - Unit ratios for individual products
    - Blending ratios for blended products
  - Plants Capacities
  - Demand Satisfaction
  - Maximum campaign length
  - Scale-up limitations

Sequencing at the Planning Level

- Traveling Salesman Problem (TSP) constraints to generate cyclic schedules

$$ygf_{g'ult} \geq \sum_{g \in G_{ul}} zzg_{gg'ult} \qquad \forall g' \in G_{ul},\ u \in U_l,\ l \in LP_l,\ t \in T$$

$$ygl_{gult} \geq \sum_{g' \in G_{ul}} zzg_{gg'ult} \qquad \forall g \in G_{ul},\ u \in U_l,\ l \in LP_l,\ t \in T$$



$$zg_{G_1G_2ult} = 1$$

$$zg_{G_2G_3ult} = 1$$

$$\vdots$$

- Cycle is broken in order to generate the sequence with minimum changeover time, but subcycles may form (not complete feasible sequence)

(Erdirik-Dogan & Grossmann, 2007)

Test Problem and Case Studies

- More than 5 plants
- Multiple reactor units in each plant
- More than 200 products
- Hundreds of customers
- Time horizon: 1 year (8,736 hours)
- Two versions
  - Version 1: Only planning – no sequencing
  - Version 2: Planning and sequencing with transitions
- Case studies
  - Solve V. 1 (single period)
  - Solve V. 2 by fixing production amounts from V. 1 (1T) solution

Problems Sizes and Units Usage Hours

	V. 1 (1T)	V. 2 fix V. 1 (1T)	V. 2 fix V. 1 (52T)
Discrete variables	12,700	24,740	736,649
Continuous variables	143,766	144,116	161,711
Constraints	100,832	115,373	702,995

- Example - six reactors with most usage
- Plants have extra capacity available

Units	V. 1 (hours)	V. 2 (1T) (hours)	V. 2 (52T) – group transitions only	V. 2 (52T) – individual product transitions	Excess hours available
Reactor-1	**7731.99**	**7735.49**	**7860.49**	**8525.74**	**210.26**
Reactor-2	7441.67	7441.92	7467.17	7943.67	792.33
Reactor-3	7077.04	7079.29	7145.29	7749.54	986.46
Reactor-4	5489.86	5493.36	5617.11	6137.36	2598.64
Reactor-5	5401.70	5403.20	5474.20	5935.45	2800.55
Reactor-6	5147.80	5148.55	5182.30	5514.05	3221.95

Observations and Next Steps

Observations

- We expected that V. 1 solution would become infeasible in V. 2
- Plants have extra capacity
  - The data might represent low customer demand
  - No info on usage hours available on each unit
- There were subcyles in some units and time periods
  - Example - Unit U32: Feasible sequence: GR2 - GR8 - GR9; subcycle GR11 <-> GR12

Next Steps

- Obtain other representative datasets from Dow
  - Get the data on usage hours available for each unit
- Explore sequencing formulations to avoid subcycles
  - Unit-Specific General Precedence (USGP) model (Kopanos *et al.*, 2009)
  - Hybrid Bilevel Decomposition and Temporal Lagrangean Decomposition to solve a large problem (Terrazas-Moreno *et al.*, 2011)

References

- Erdirik-Dogan, M., & Grossmann, I. E. (2007). *Planning Models for Parallel Batch Reactors with Sequence-Dependent Changeovers*. **AIChE Journal**, 53(9), 2284-2300.
- Kopanos, G. M., Laínez, M. J., & Puigjaner, L. (2009). *An Efficient Mixed-Integer Linear Programming Scheduling Framework for Addressing Sequence-Dependent Setup Issues in Batch Plants*. **Industrial & Engineering Chemistry Research**, *48*(13), 6346–6357.
- Terrazas-Moreno, S., Trotter, P. A., & Grossmann, I. E. (2011). *Temporal and spatial Lagrangean decompositions in multi-site, multi-period production planning problems with sequence-dependent changeovers*. **Computers & Chemical Engineering**. doi:10.1016/j.compchemeng.2011.01.004