# Slot-Based Integrated Planning and Scheduling of Batch Processes

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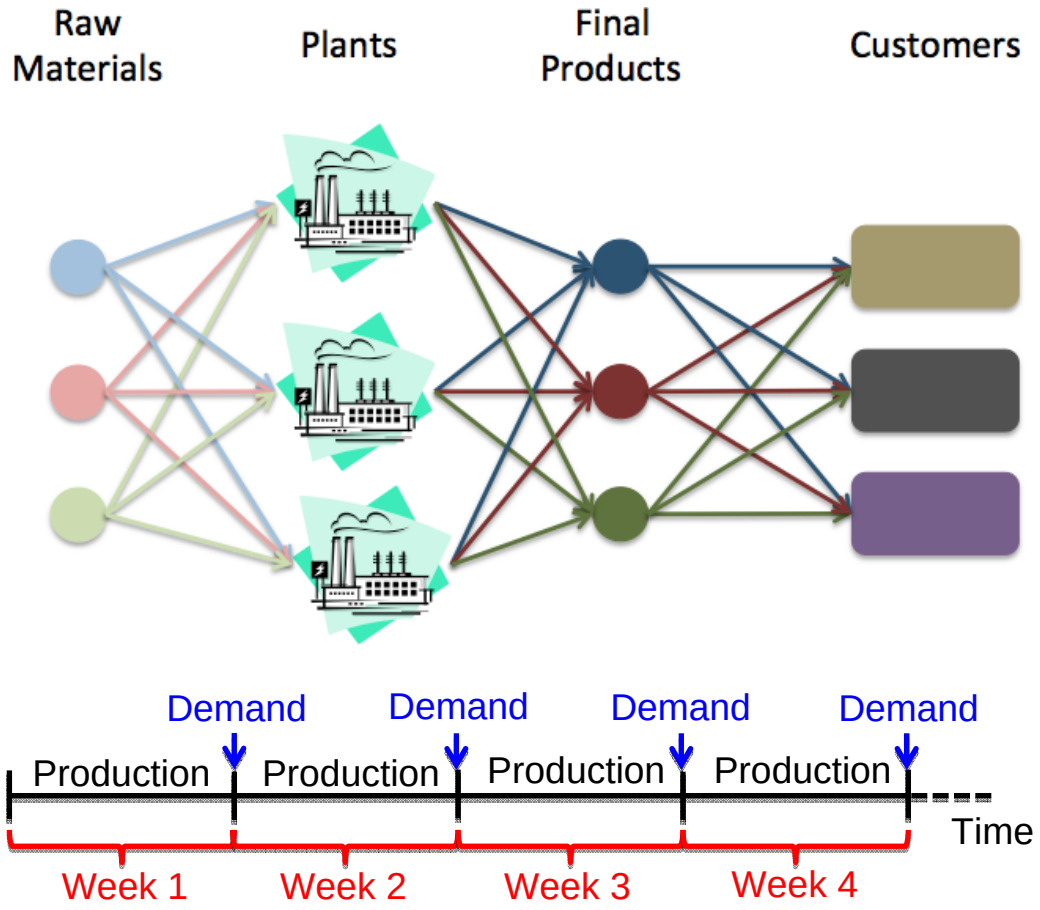
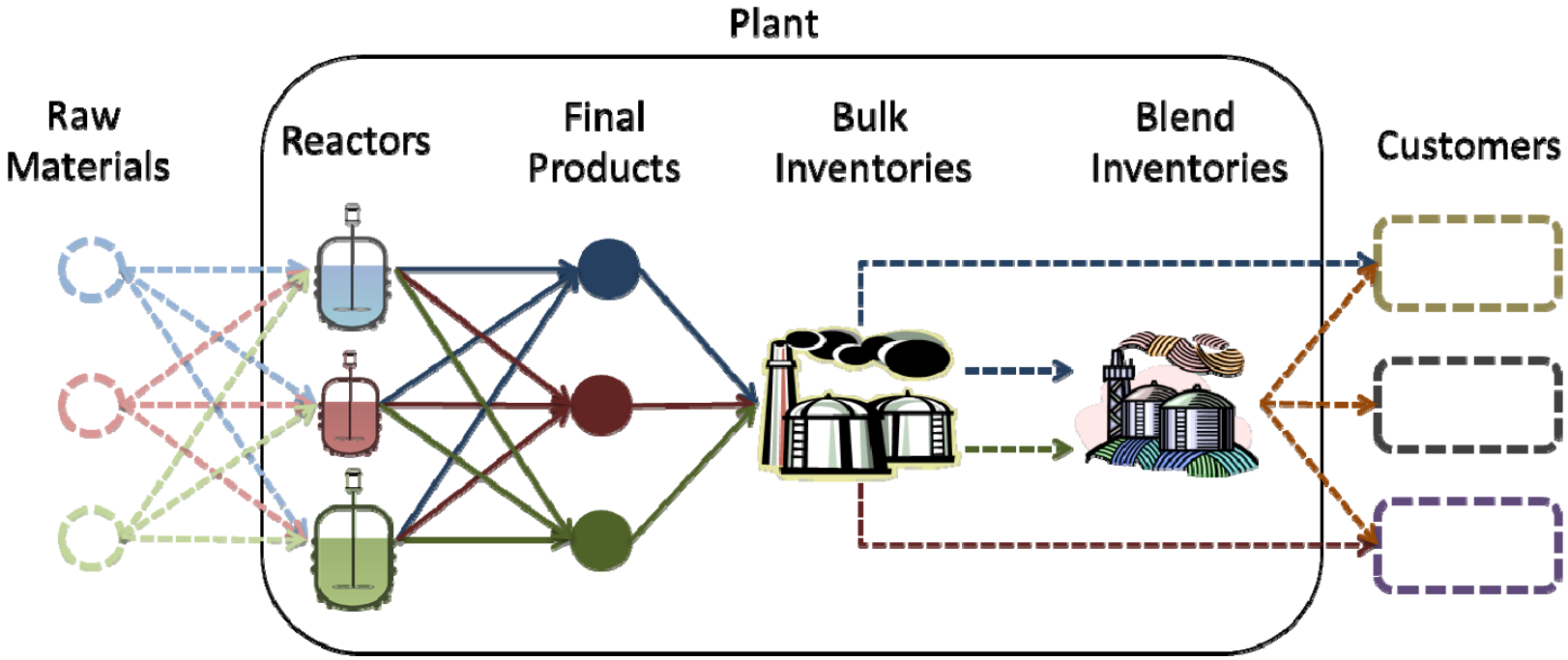
# Original Problem




- Multi-period integrated planning and scheduling of multi-product batch plants located in multiple sites

# Single-Site Batch Plant




- Batch units operating in parallel
- Sequence-dependent changeovers between products groups
- A subset of products are blended
- Blending ratios are specified
- Demands are specified at the end of time periods (weeks)

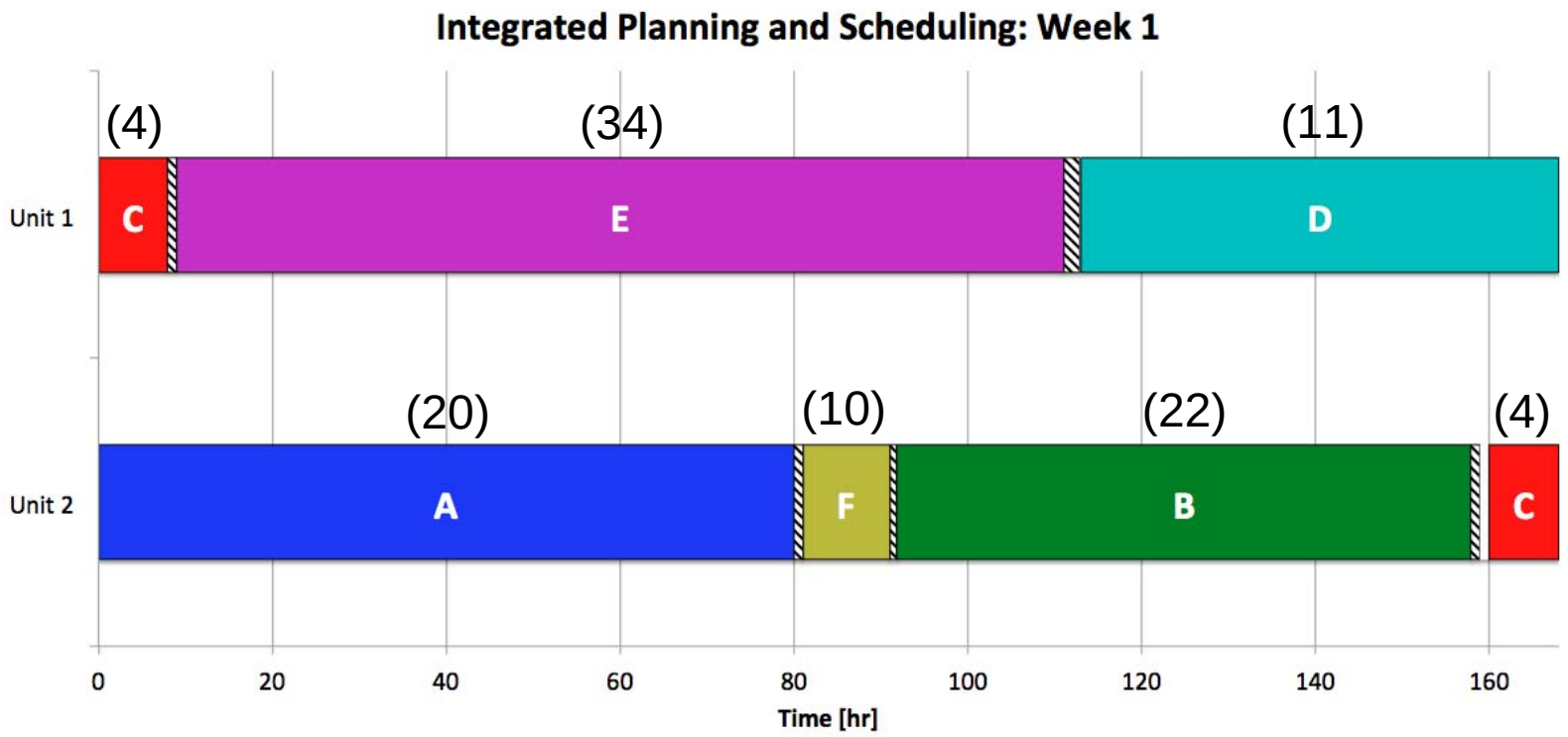
# Problem Statement

- **Given**
  - Number of products to be produced (subset by blending)
  - Batch sizes and fixed processing times
  - Sequence-dependent changeover times and costs
  - Transportation and inventory costs
  - Selling prices
  - Forecast demands over a time horizon (lower bounds)
- **Determine**
  - Production amounts for each product in order to satisfy demands at each time period
  - Allocation of products to units at each time period
  - Detailed sequencing of products in each unit
- **Objective Function**
  - Maximize: Profit
    - Income from Sales
    - Operating, Transportation, Inventory, Changeover costs

# Solution Approach

- **Integrated Planning and Scheduling**
  - Bilevel Algorithm
    - Two subproblems:
      - Upper Level Planning (ULP) Problem
      - Lower Level Scheduling (LLS) Problem
- **Scheduling**
  - Two slot-based formulations were investigated
    - Single-Operation Slots (SOS) [Erdirik-Dogan *et al.*, 2008]
    - Multi-Operation Slots (MOS) [Mouret *et al.*, 2011]
- **Planning**
  - Detailed Planning (DP) [Erdirik-Dogan *et al.*, 2007]

# Results for Integrated Planning and Scheduling




| Problem | Discrete Variables | Continuous Variables | Equations | Non-zero Elements | Nodes | CPU [s] |
|---|---|---|---|---|---|---|
| ULP (DP) | 1,320 | 2,348 | 3,313 | 9,680 | 12,031 | 9.5 |
| LLS (SOS) | 2,400 | 3,644 | 3,863 | 12,006 | 0 | 0.9 |
| FS (SOS) | 2,784 | 4,004 | 4,151 | 13,374 | 48,175 | 162.265 |

# Conclusions

- **Batch Scheduling**
  - SOS formulation is computationally faster than MOS despite having more 0-1 variables
  - SOS model resulted in a tighter formulation
- **Integrated Planning and Scheduling**
  - Bilevel algorithm enables tackling larger problems
  - ULP problem and LLS problem converged to 0.5% in the 1$^{st}$ iteration
  - Orders of magnitude reduction in CPU time *vs.* full space

# References


- Erdirik-Dogan, M., & Grossmann, I. E. (2007). *Planning Models for Parallel Batch Reactors with Sequence-Dependent Changeovers*. **AIChE Journal**, 53(9), 2284-2300.

- Erdirik-Dogan, M., & Grossmann, I. E. (2008). *Slot-Based Formulation for the Short-Term Scheduling of Multistage, Multiproduct Batch Plants with Sequence-Dependent Changeovers*. **Industrial & Engineering Chemistry Research**, 47(4), 1159-1183.

- Mouret, S., Grossmann, I. E., & Pestiaux, P. (2011). *Time representations and mathematical models for process scheduling problems*. **Computers & Chemical Engineering**, 35(6), 1038-1063. Elsevier Ltd.