Opportunities & Challenges for Research Collaboration Between Academia and Industry

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Princeton University – ATOFINA Chemicals, Inc.

Collaboration Roadmap

Time

- **Novel continuous-time formulations for short-term scheduling**
  Ierapetritou and Floudas, 1998a,b; Ierapetritou, Hené and Floudas, 1999.
- **Spring 1999** Short-term scheduling: "Proof of Concept"
  - Professor Christodoulos A. Floudas, Xiaoxia Lin
  - Dr. Nikola Juhasz
  - Early success: project presented to the Board of Directors
- **January 2000** Medium-term scheduling
  - Theoretical framework
  - Computational studies
  - Implementation → PlantScheduling
- **January 2001** Beta-testing of PlantScheduling
  - Sweta Modi
- **Fall 2001** On-site application of PlantScheduling
  - Ronald Sanders
- **Fall 2002** Reactive scheduling

ATOFINA Plant

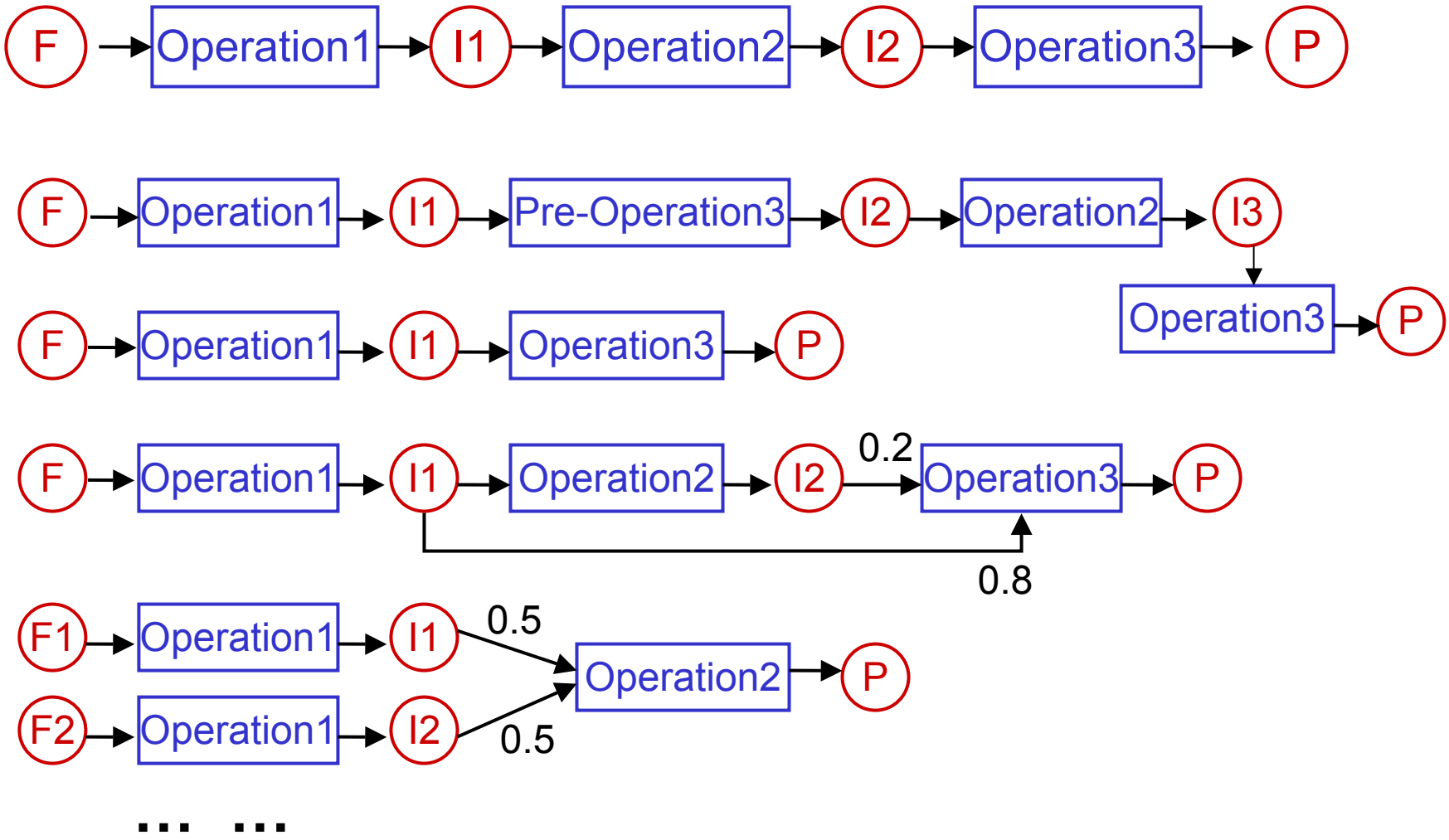
- Five categories, near 60 different products
- Basic operations: Operation 1, Operation 2, and Operation 3
- Units: four Type 1 units (batch), three Type 2 units (continuous) and three Type 3 units (batch)
- Scheduling horizon: ~ one month
- Unlimited storage capacity

- Given:
  - processing sequences
  - unit capacities, suitabilities, processing times/rates
  - inventory of products and intermediate materials
  - demands: amount, due date and customer priority

- Objective: generate optimal schedules

Process Alternatives

State-Task Network (STN) representation (Kondili et al., 1993)



Novel Continuous-Time Mathematical Formulations for Process Scheduling

Ierapetritou and Floudas (1998a,b); Ierapetritou, Hené and Floudas (1999)
Lin and Floudas (2001); Lin, Floudas, Modi, and Juhasz (2002)
Lin, Chajakis and Floudas (2003)

- Continuous-time representation
- Original concept of event points (beginning of a task or utilization of a unit) and formulation of special timing constraints
- Variable (batch-size dependent) processing times
- General batch, continuous and semi-continuous processes
- Demands with intermediate due dates
- Mixed-Integer Linear Programming (MILP)
- Lead to smaller size models in terms of the number of binary variables; require less computational effort; give better solutions compared to previous approaches

Initial Study: Proof of Concept

Spring 1999

- Short-term scheduling on weekly basis
- Case study I
- Collect data on process operations
- Model formulation
- Interactions between Princeton University and ATOFINA Chemicals, Inc.
  - Visits to plant (many times), discussions with plant personnel (plant manager, demand manager, scheduler, etc.)
  - Collaborator: Dr. Nikola Juhasz
- Early success
  - Effective modeling and optimization
  - Increase of unit utilization and demand satisfaction level
- Leads to further full-scale collaboration

Development of Theoretical Framework

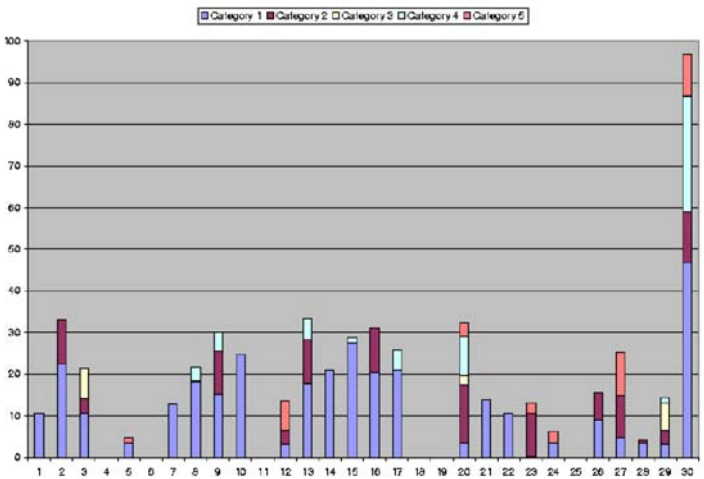
January 2000

- Medium-Term Scheduling on monthly basis
- Decomposition framework – rolling time horizon approach
  - Two-level decomposition model
  - Effective short-term scheduling model
- Validation of data and model
- Incorporation of additional considerations
  - Campaign mode production
  - Grouping of black/non-black products
- Interactions between Princeton University and ATOFINA Chemicals, Inc.
  - Explain methodology and computational study results
  - Obtain feedback

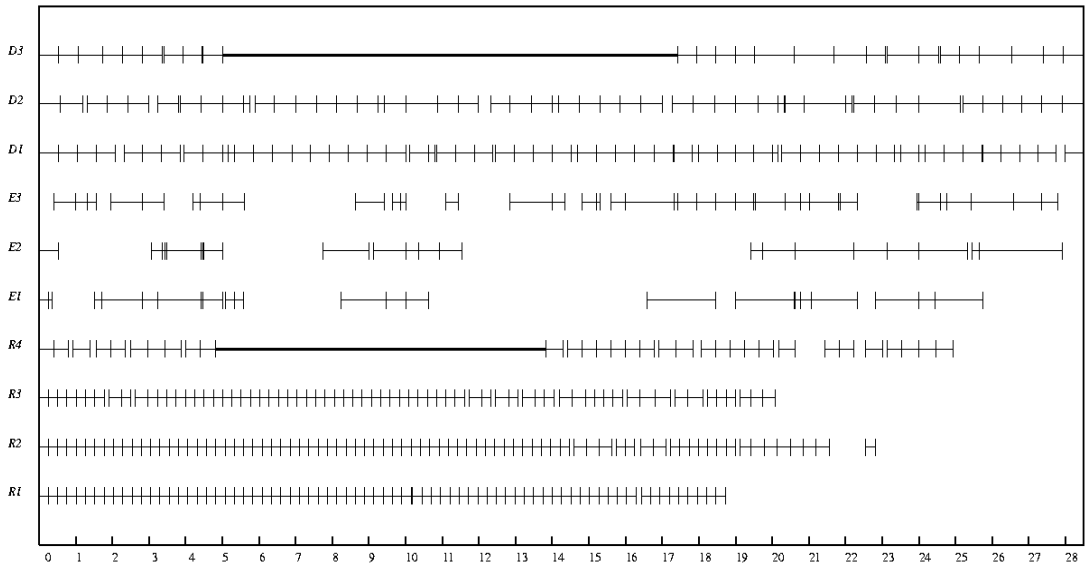
Computational Studies

January 2000

- **Case Study 2: 36 products, 30 days**
- **Effectiveness of overall methodology demonstrated**
  - **Increased overall production and demand fulfillment**
  - **Efficient unit utilization**
  - **Identification of production bottleneck**



Distribution of demands

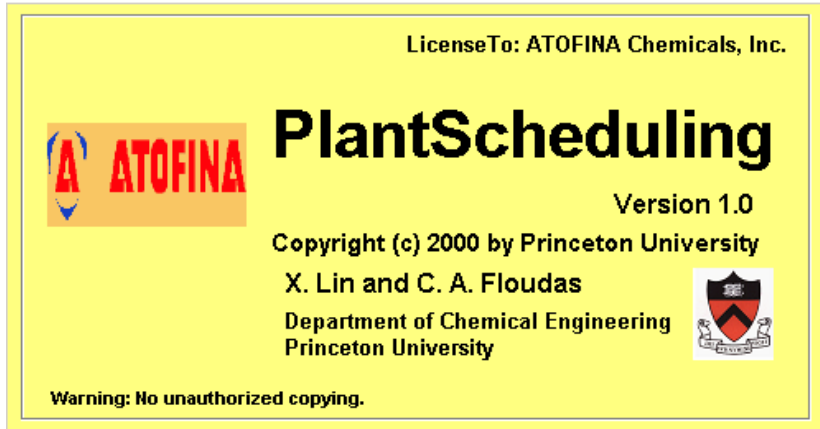


Schematic overall schedule

Implementation: Integrated Software System

May 2000

- Six main functional modules
  - Data manipulation
  - Campaign-mode production scheduling
  - Decomposition
  - Short-term scheduling
  - Results output
  - Reactive scheduling



- Graphical user interface implementation
  - Developed in extensive Visual Basic
  - Database support – Microsoft Access
  - MILP model formulation – MINOPT (Schweiger and Floudas, 1998)
  - MILP model solution – CPLEX

Beta-Testing and On-Site Application

- **Extensive beta-testing**: 9 months — January 2001
  - Sweta Modi
  - Close interactions
  - Constructive feedback and suggestions
- **Used by actual scheduler** — Fall 2001 – present
  - Ronald Sanders
  - Requires intensive tutorials
  - Model generated schedules used to guide actual production
- **Reactive scheduling** — Fall 2002 – present
  - Unit shut-downs
  - Demand changes

Challenges

- Understand the real operational problem
  - Collection of data
  - Model the process and remodel (many times)
  - Establish good interactions
    - Dr. Nikola Juhasz; Sweta Modi
  - Support from the schedulers and the plant management
    - work together
- Help scheduler understand the methodology

⇒ Short-term scheduling

⇒ Medium-term scheduling

⇒ Reactive scheduling

Challenges (cont'd)

- Incorporate special types of constraints
  - Consecutive batches in reactor
  - Black/natural products grouping
  - Campaign-mode production
- Develop fully customized graphical user interface
  - User friendly
- Validation: 18 months of beta-testing
  - Sweta Modi (9 months)
  - Ronald Sanders (15 months)
- Changes in industrial personell in the middle of the project

  Sweta Modi $\Rightarrow$ Ronald Sanders

Opportunities

- New approach for short-term scheduling (Academic)
- Opportunities for Princeton University :
  - Real industrial applications ⇒ Further new developments
    - Medium-term scheduling
    - Reactive scheduling
  - Funding to Princeton University
  - Potential impact

  Opportunities for ATOFINA Chemicals, Inc. :
  - Introduce new state of the art technology
  - Increase productivity
- Experience gained for development: general processes

⇓

COSMOS

(COntinuous-time Scheduling of Manufacturing OperationS)

Conclusions

- Collaboration between

  Princeton University and ATOFINA Chemicals, Inc

  - Production scheduling of a multiproduct polymer plant
  - Initial study ("proof of concept") → theoretical developments and computational studies → software development → beta-testing and on-site application
- Challenges during the collaboration process
  - Understanding and collection of data
  - Development of customized software
  - Validation of data, model and overall methodology
- Opportunities
  - Benefits for Princeton University
  - Benefits for ATOFINA Chemicals, Inc.
  - General processes development: COSMOS