Models and Simulation for Bulk Gas Production and Distribution

Jeff Linderoth

Dept. of Industrial and Systems Engineering
Univ. of Wisconsin-Madison
linderoth@wisc.edu

Wasu Glankwamdee

ISE Department
Lehigh University

Jim Hutton
Peter Connard
Jierui Shen
Air Products

COR@L
COMPUTATIONAL OPTIMIZATION
RESEARCH AT LEHIGH

AIR PRODUCTS

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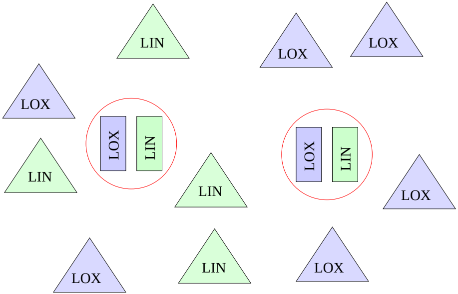
Liquid Bulk Gas Production-Distribution

- Sites $\mathcal{S}$
- Products $\mathcal{P} = \{\text{LOX}, \text{LIN}\}$
- Customers $\mathcal{C}$



Planning Problem

How should one set production levels at the sites $s \in \mathcal{S}$ and sourcing decisions (amount delivered from $s \in \mathcal{S}$ to $c \in \mathcal{C}$) in order to meet customer demand at minimum cost?

What Did We Do

Research Objectives

1. What is benefit of considering finer-grain model
2. What is benefit of stochastic/robust planning models.

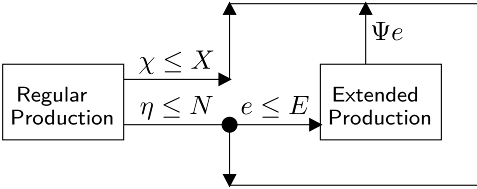
Research Deliverables

1. Optimization Models for Production/Distribution
2. Simulation Engine for Production/Distribution
   - Hooked directly to optimization models (XPRESS-MP)
3. Formats and input for “real data” from AP

Bulk Gas Wrinkles

Production

- Most sites operate in two modes: Regular and extended
- Can change "fraction" of LOX as opposed to LNI



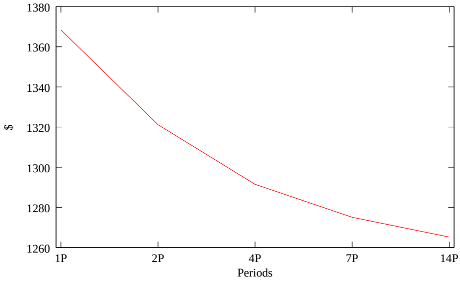
Competitor Arrangements

- Enter contractual "take-or-pay" arrangements with competitors
- Allowed to remove (equal) fixed amount of product from each other's sites:

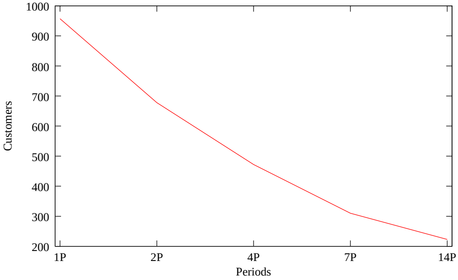
Impact of Finer Grain – Random Instances

- Pictures show simulated total cost and customer outages/month as a function of the number of periods in the planning model

Cost

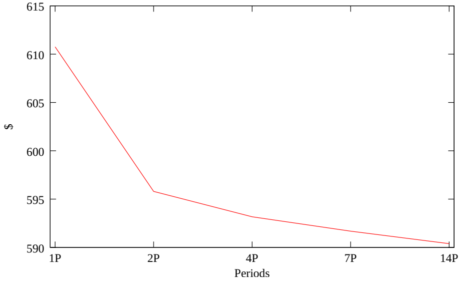


Outages

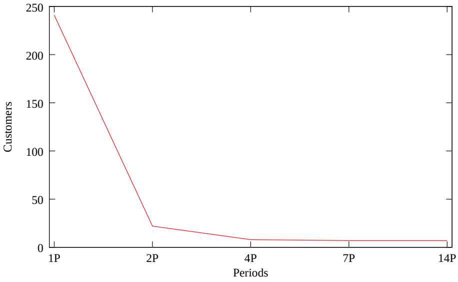


Impact of Finer Grain – Real Instance

Cost



Outages



What's Next? (Actual Slide from 2006)

Transfer Technology to Air Products

- Run on Real Data
  - Need to write code to instantiate objects from data files

Keep Considering Uncertainty!

- Minimax Model
- Robust Optimization Model
- Stochastic model
- Disruption Planning: consider more “extreme” scenarios. Help build “contingency lists” for sourcing decisions.

Hooray for Us!

- We did all of these things, save for the last one—A focus for 2008!

Opt. Under Uncertainty Primer

Optimization Problem

$$\min_{x \in X} f(x)$$

- The real cost of doing bizness is $F(x, \omega)$
  - x: Variables you control
  - ω : Variables you don't

Robust (Minimax) Optimization

$$\min_{x \in X} \max_{\omega \in \mathcal{U}} F(x, \omega)$$

- $\omega \in \mathcal{U}$: Some uncertainty set

Stochastic Optimization

$$\min_{x \in X} \mathbb{E}_{\omega} F(x, \omega)$$

- $\omega \in \Omega$ for some probability space $(\Omega, \mathcal{F}, \mathbb{P})$.

What's Next? A Stochastic Model

The World Is Random!

- In the planning model, make parameters functions of some random variable ω

- $M_{st}(\omega), N_{st}(\omega)$: Production Capacity Uncertain
- $B_{pct}(\omega)$: Demand for product p from customer c in period t is uncertain
- $z_{prt}(\omega)$: Amount of product p contract partner takes out at site r in period t is uncertain. Typically $\sum_{r \in \mathcal{R}} \sum_{t \in \mathcal{T}} z_{prt}(\omega) = \Phi_p$

We Love Σ, Yes We Do!

$$\min \sum_{p\in\mathcal{P}}\sum_{s\in\mathcal{S}}\sum_{n\in\mathcal{N}} \eta_n(\alpha_{psn}x_{psn}+\beta_{psn}e_{psn}+\gamma_{ps}I_{psn})+\sum_{p\in\mathcal{P}}\sum_{s\in\mathcal{S}}\sum_{c\in\mathcal{C}}\sum_{n\in\mathcal{N}}\eta_n(f_{sc}y_{pscn})+\sum_{p\in\mathcal{P}}\sum_{c\in\mathcal{C}}\sum_{n\in\mathcal{N}}\eta_n(\delta \tag{1a}$$

$$\text{s.t} \quad \sum_{p\in\mathcal{P}} x_{psn} \leq M_{sn}, \quad \forall s\in\mathcal{S},\ \forall n\in\mathcal{N} \tag{1b}$$

$$\sum_{p\in\mathcal{P}} e_{psn} \leq N_{sn}, \quad \forall s\in\mathcal{S},\ \forall n\in\mathcal{N} \tag{1c}$$

$$x_{psn} \leq \Lambda_p M_{sn}, \quad \forall p\in\mathcal{P},\ \forall s\in\mathcal{S},\ \forall n\in\mathcal{N} \tag{1d}$$

$$e_{psn} \leq \Lambda_p N_{sn}, \quad \forall p\in\mathcal{P},\ \forall s\in\mathcal{S},\ \forall n\in\mathcal{N} \tag{1e}$$

$$\sum_{s\in\mathcal{S}} y_{pscn} + u_{pc,\rho(n)} - v_{pc,\rho(n)} - B_{pcn} = u_{pcn} - v_{pcn}, \quad \forall p\in\mathcal{P},\ \forall c\in\mathcal{C},\ \forall n\in\mathcal{N} \tag{1f}$$

$$\sum_{c\in\mathcal{C}} y_{prcn} - I_{pr,\rho(n)} - x_{prn} - e_{prn} + I_{prn} = -z_{prn}, \quad \forall p\in\mathcal{P},\ \forall r\in\mathcal{R},\ \forall n\in\mathcal{N} \tag{1g}$$

$$\sum_{c\in\mathcal{C}} y_{pscn} - I_{ps,\rho(n)} - x_{psn} - e_{psn} + I_{psn} = 0, \quad \forall p\in\mathcal{P},\ \forall s\in\mathcal{S}\backslash\mathcal{R},\ \forall n\in\mathcal{N} \tag{1h}$$

$$\sum_{q\in\mathcal{Q}} x_{pqn} + \phi_{pn} = \phi_{p,\rho(n)}, \quad \forall p\in\mathcal{P},\ \forall n\in\mathcal{N} \tag{1i}$$

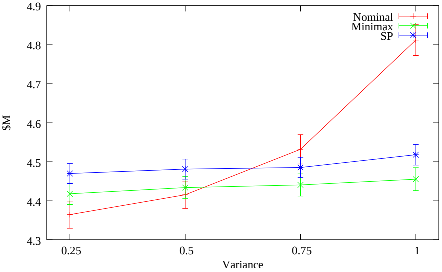
$$\sum_{p\in\mathcal{P}}\sum_{c\in\mathcal{C}} d_{sc}y_{pscn} \leq D_{sn}, \quad \forall s\in\mathcal{S},\ \forall n\in\mathcal{N} \tag{1j}$$

$$\sum_{c\in\mathcal{C}} d_{sc}y_{pscn} \leq K_{psn}, \quad \forall p\in\mathcal{P},\ \forall s\in\mathcal{S},\ \forall n\in\mathcal{N} \tag{1k}$$

$$I_{psn} \leq U_{ps}, \quad \forall p\in\mathcal{P},\ \forall s\in\mathcal{S},\ \forall n\in\mathcal{N} \tag{1l}$$

Random Instances—Total Cost

- Chart shows simulated total cost of different policies: x_N, x_{MM}, and x_{SP}, as the "true" variance of customer demand varies



- Surprising Result: Minimax does better in simulation than SP.
- Only a "small" (like 5-10) outcomes considered

A Final Use!

- Having a realistic, reliable simulator can be very useful.
- AP wanted to answer the question: How much is the "take-or-pay" contract worth to us?

	Total Cost ($M)	Production Cost ($M)	Delivery Cost ($M)	# Outages
With Contract	2.03	1.45	0.58	7
No Contract	2.06	1.45	0.61	7

EWO Outcomes

Great Outcomes

- Simulation code and optimization models turned over to AP
- Research shows possible benefits to considering finer grain models
- Research shows possible benefit to more robust PD planning models
- Research shows the benefit of combining simulation with optimization

Even Better Outcomes

- Jerry hired by AP
- We wrote a paper! :-)

Lehigh EWO – 2008 and Beyond!

- Will continue the existing research effort for developing computational tools for EWO problems
- The major contribution of this project will allow for efficient optimization of large-scale process industry problems
- The models will address the problem of coordinated optimization across different functions (purchasing, manufacturing, distribution, and sales), across different geographical areas, and across different levels (strategic, tactical, and operational) in a company

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Lehigh Projects

- Air Products: Design and optimization of supply chain under risk of disruptions. Electricity Contract Pricing.