Designing Flexible and Robust Supply Chains

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IERC Dallas, Spring 2001

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Overview

- Supply chain design problem
- Flexibility and robustness
- Hierarchical stochastic design procedure
- Computational example
- Conclusions

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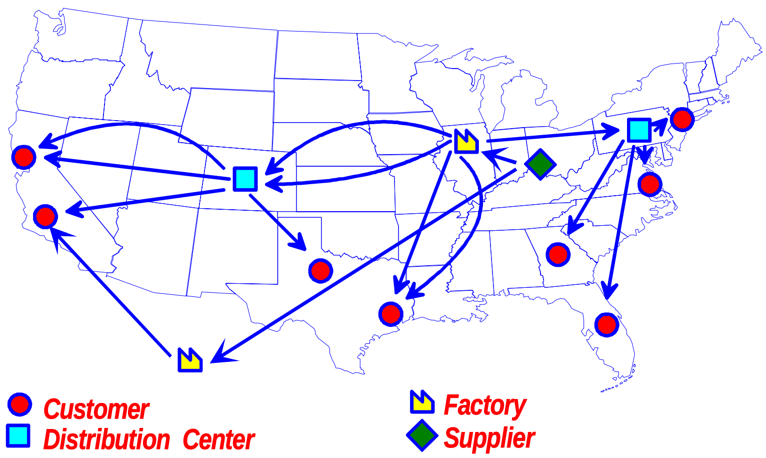
Supply Chain Networks



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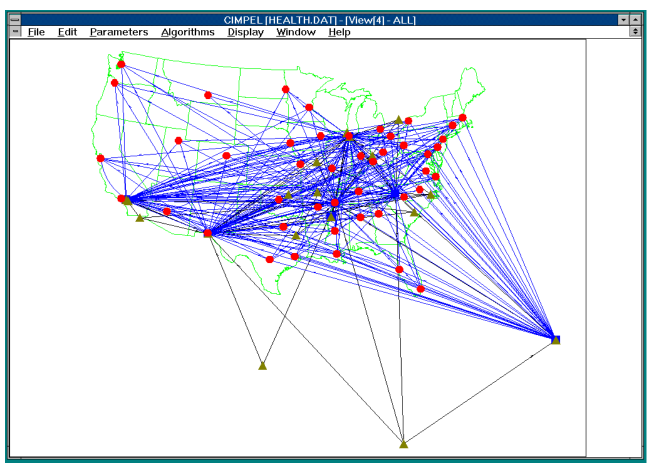
Single Period, Single Echelon, Multicommodity Example



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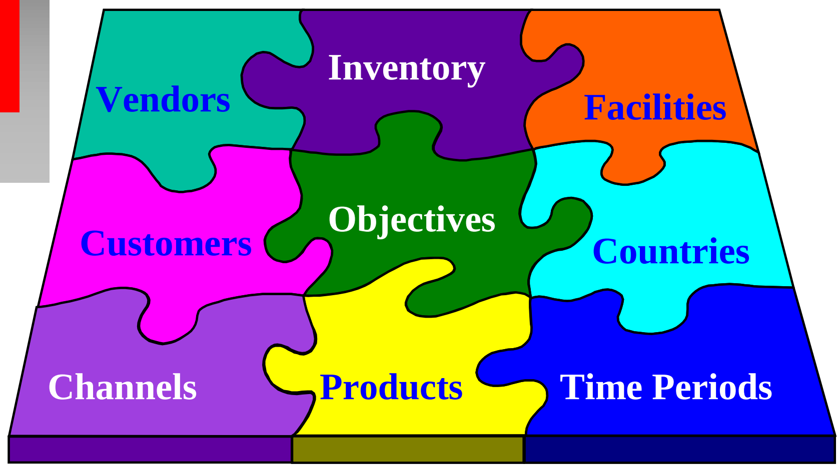
Supply Chains Designs Integrated and Comprehensive



Supply Chain Design Problem

- *Multicommodity, multiperiod, multi-echelon, capacitated network flow problem (nodes, arcs)*
- *Decision variables*
  - *Binary status variables for facility, technology, machine*
  - *Continuous material flow variables*
- *Objective function, constraint matrix, right-hand side all can be stochastic*

Supply Chain Design Objectives

- Cost minimization
- Return on investment maximization
- Profit maximization
- Flexibility
- Responsiveness
- Robustness
- Usually conflicting

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Data Sources

- Business operating documents
  - Sales orders, customer data, freight bills
- Business documents
  - Annual report, accounting (activity-based-costing)
- Published reference data
  - Trade magazines, census data, press
- Mostly imprecise forecasts

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Design of Robust and Flexible Supply Chains

- Change in the mission and data is inevitable, but only techniques are sensitivity and scenario analysis
- No scientific analysis or design methodology for such large problems
- Needed measures of
  - Flexibility (configuration feasibility)
  - Robustness (quality of objective)

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Research Review

- Extensive literature on deterministic or scenario-based supply chain design
- Flexibility definitions in manufacturing research (FMS) appear not applicable
- Some stochastic optimization for exchange rates in global systems

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Robustness and Flexibility

- Relative Robustness, Kouvelis (1997)

$$\max_{s \in S} \left\{ \frac{z_s\left(x_R\right) - z_s^*\left(x_s^*\right)}{z_s^*\left(x_s^*\right)} \right\}$$

- Flexibility, Beamon (1998)
  - unused capacity in a configuration

Definitions

- Efficiency = minimal cost for the execution of a particular mission (planned scenarios)
- Flexibility = minimal cost increase for execution of unanticipated conditions (demand and capacity changes)
- Robustness = minimal cost increase execution of unanticipated conditions (price changes)

Hierarchical Stochastic Design Algorithm

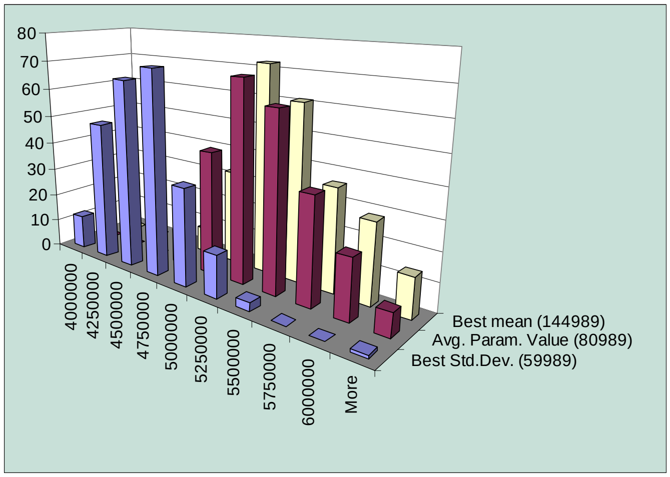
- Select a limited number of feasible facility configurations
- For each configuration
  - Sample parameters from distributions
  - Solve linear network flow problem
  - Compute expected value and variance
- Select "best" configuration
  - Weighted objective or efficiency frontier

Hierarchical Two-Stage Formulation

$$\begin{aligned} Min \quad & cx + dy \\ s.t. \quad & Ex + Fy \le h \\ & Hx \le g \\ & x \in \{0,1\}, y \ge 0 \end{aligned}$$

$$\begin{aligned} Min \quad & cx + E\left[Q(x,\xi)\right] \\ s.t. \quad & Hx \le g \\ & x \in \{0,1\} \end{aligned} \qquad Q(x,\xi) = \begin{aligned} Min \quad & dy \\ s.t. \quad & Fy \le h - Ex \\ & y \ge 0 \end{aligned}$$

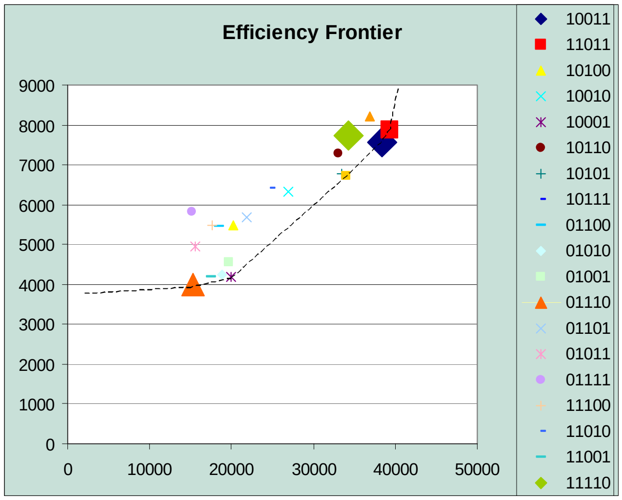
Second Stage Profit Distributions (Medium Example)



Multicriteria Formulation

$$
\begin{aligned}
Min \quad & cx + E\left[Q(x,\xi)\right] + \alpha \cdot SD\left[Q(x,\xi)\right] \\
s.t. \quad & Hx \le g \\
& x \in \{0,1\}
\end{aligned}
$$

Multi-objective Criteria and Efficiency Frontier (Medium)



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Approximations

$$E\left[Q(x,\xi)\right] \approx \frac{1}{N}\sum_{i=1}^{N} Q\left(x,\xi^{i}\right)$$

$$SD\left[Q(x,\xi)\right] = \sqrt{Var\left[Q(x,\xi)\right]}$$

$$Var\left[Q(x,\xi)\right] \approx \frac{1}{N}\sum_{i=1}^{N} Q^{2}\left(x,\xi^{i}\right) - \left\{\frac{1}{N}\sum_{i=1}^{N} Q\left(x,\xi^{i}\right)\right\}^{2}$$

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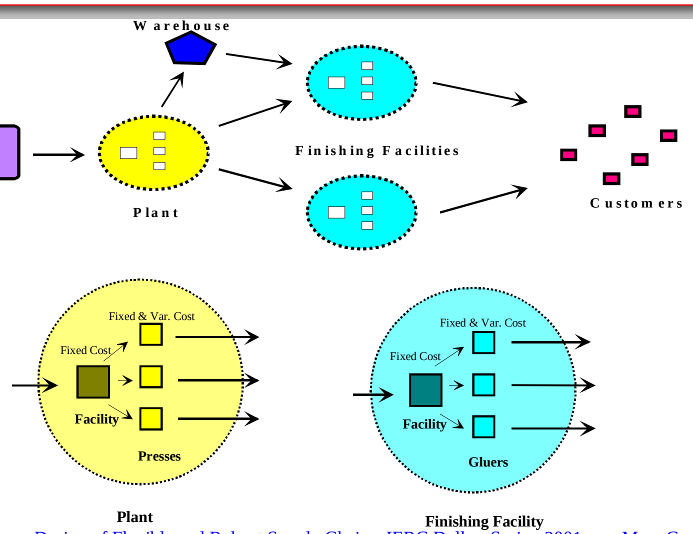
Two Stage Supply Chain with Machine Resources



Cardboard Packaging Manufacturer

- *3 seasons, 2 stage manufacturing*
- *13 products, 714 customers*
- *87 production lines (machines)*
- *3738 transportation channels*
- *48888 continuous flow variables*
- *140 binary (major) site and (minor) machine variables*

Parameters

- Capacities, supplies, transportation, demand, and costs all log-normally distributed
  - 10 % coefficient of variation
- 400 Mhz Pentium III, CPLEX 7.0
- 41 seconds per single scenario deterministic case

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Design of Experiments

- # Scenarios in first stage MIP
- # Replications of first stage MIP
- # Replications of second stage MCNF
- Coefficient of variation (10%, 30%)

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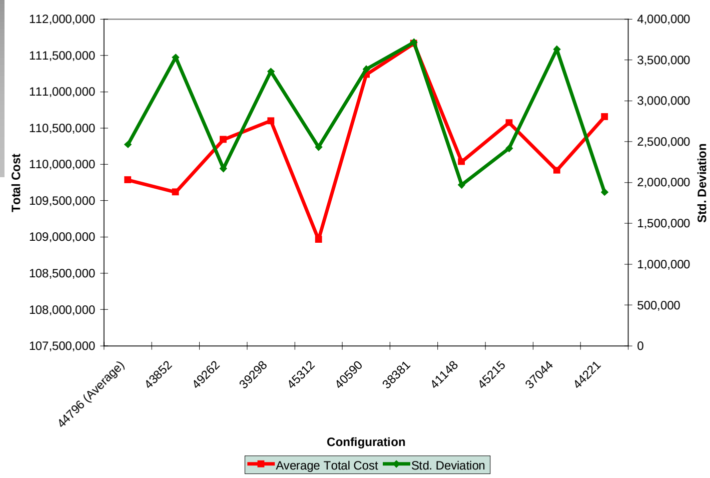
Case (1, 10, 10)



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Case (1, 10, 10) Statistics

- Computation times
  - Expected value problem 42 s
  - First stage replications 411 s
  - Second stage replications 1019 s
  - Total 1578 s
- Variation
  - 10 (+1) configurations

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Case (1, 10, 10) Robustness

#	Major Plant Decision	Configurations	Total
1	10101011	44796, 43852, 45215	3
2	11101011	39298	1
3	10111111	49262, 44221	2
4	10101111	45312, 40590, 41148	3
5	10111011	38381, 37044	2

#	Major FF Decision	Configurations	Total
1	101011011	44796, 43852, 45312,	6
		40590, 41148, 45215	
2	101010011	39298	1
3	101111011	49262, 37044	2
4	101110011	38381	1
5	111111011	44221	1

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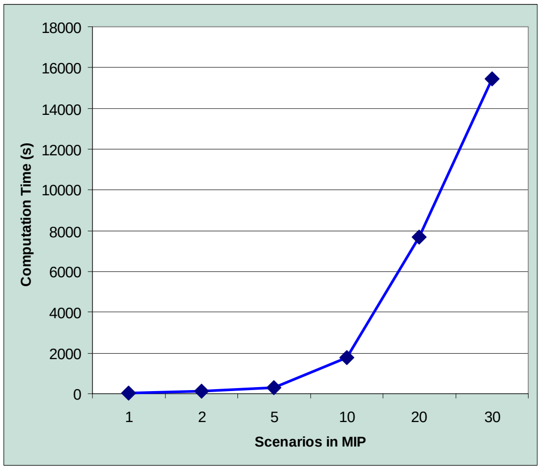
First Stage Single MIP Computation Times



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Computation Times and Robustness Summary

	(1, 10, 10)	(2, 5, 10)	(5, 5, 10)	(10, 18, 10	(20, 9, 10)	(30, 6, 10)
Single MIP	42	128	287	1,770	7,675	15,470
First Stage	411	639	1,437	31,865	69,076	92,819
Second Stage	1,019	1,275	4,689	1,750	927	648
Total Time	1,578	1,918	6,651	34,962	71,359	94,805
	(1, 10, 10)	(2, 5, 10)	(5, 5, 10)	(10, 18, 10	(20, 9, 10)	(30, 6, 10)
Configurations	11	6	6	19	10	7
1-Stage Sites	5			4	4	1
2-Stage Sites	5			2	2	1

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Computational Experiment Conclusions

- Designing for average parameters yields a dominated configuration
- Increasing scenarios in first stage MIP increases robustness and computation times
- Report multi-criteria solutions diagram
- Significant computational burden for larger cases and many scenarios

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Conclusions

- *Good definitions and measures for flexibility and robustness are lacking*
- *Current methodology is deterministic design and sensitivity or scenario analysis*
- *Hierarchical design algorithm performs very well in tested cases*
- *Computational issues for larger industrial cases*

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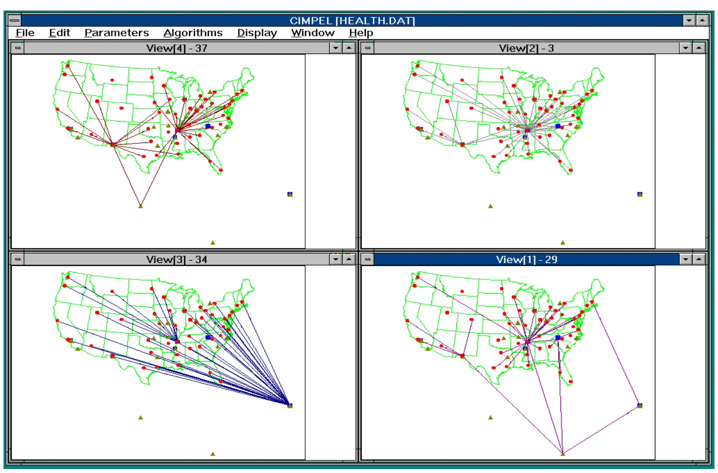
...and Configuration by a Current Design Tool



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Design Tools for the Next Century

Supply Chain Design Challenges

- Integrated models are large and complex
  - More tactical effects (seasonal, inventory)
- Multi-objective performance measures
  - Cost/profit, flexibility, and responsiveness tradeoffs
- Strategic design as a continuous effort
  - Models, data, algorithms

Supply Chain Design Challenges Continued

- Technology transfer to logistics professionals and students
  - Toy cases and black-box software

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Supply Chain Modeling Challenges

- Multiple periods, combined with tactical
  - Periodic and seasonal demand
  - Dynamic strategic systems
- Global
  - Taxes and profit realization
  - Local contents, duty drawback
- Stochastic
  - Flexibility, robustness, risk, scenarios

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Supply Chain Solution Algorithms Challenges

- Large scale models
- Non-linear models
- Stochastic models
- Standard MIP linear algorithms cannot solve very large cases
- NL-MIP or stochastic algorithms only for small cases or nonexistent

Thank You
Can I Answer Any Questions?