Designing Flexible and Robust Supply Chains

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Overview

- Supply Chain Design Problem
- Flexibility and Robustness
- Hierarchical Stochastic Design Procedure
- Computational Example
- Conclusions

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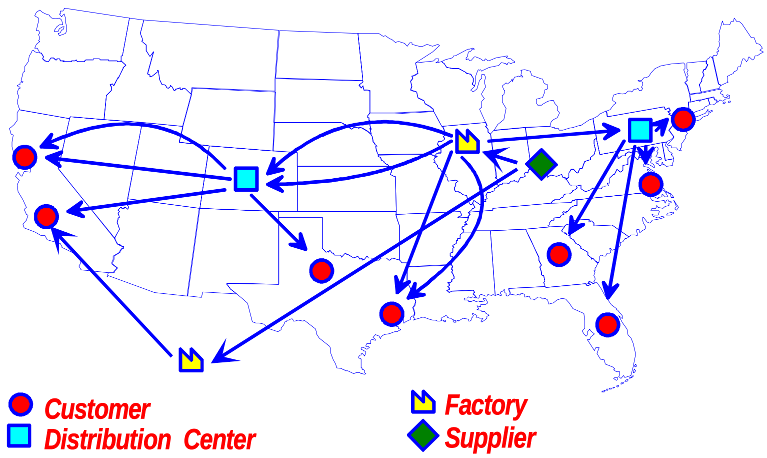
Supply Chain Networks



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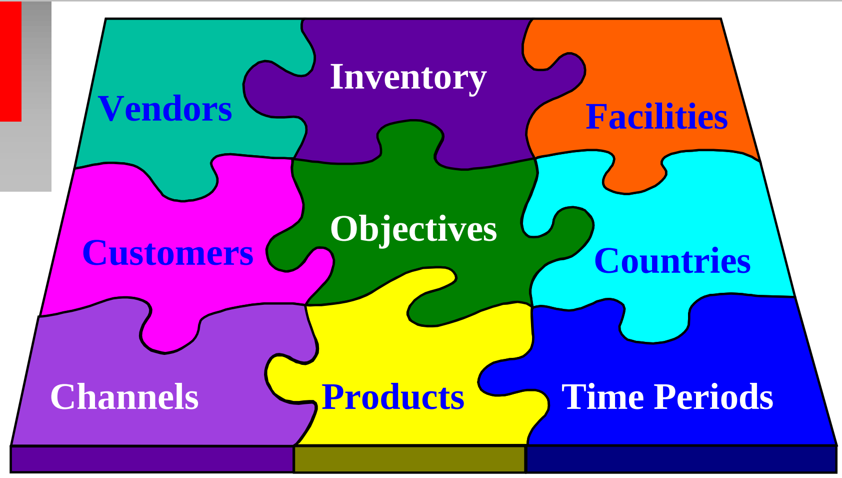
Supply Chains Designs
Integrated and Comprehensive



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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

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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

Design of Robust and Flexible Supply Chains

- Change in the mission and data is inevitable, but only technique is sensitivity analysis
- No scientific analysis or design methodology for such large problems
- Needed Measures of
  - Flexibility (Configuration)
  - Robustness (Costs)

Research Review

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

Robustness and Flexibility

- Relative Robustness, Kouvelis (1997)

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

- 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

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

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

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Multi-objective Formulation

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

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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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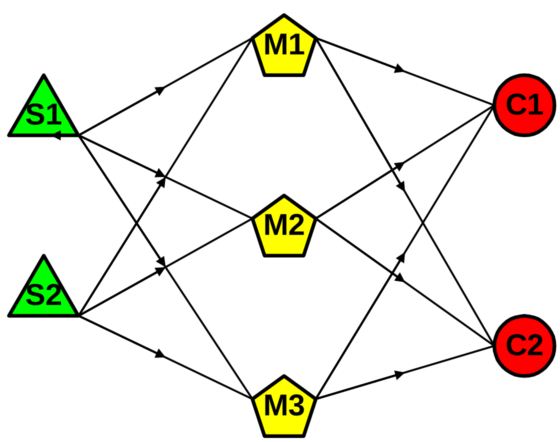
Supply Chain Example



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Parameters

- Capacities, supplies, transportation, demand all normally distributed
- 21 feasible facility configurations
- 1000 replications for each configuration

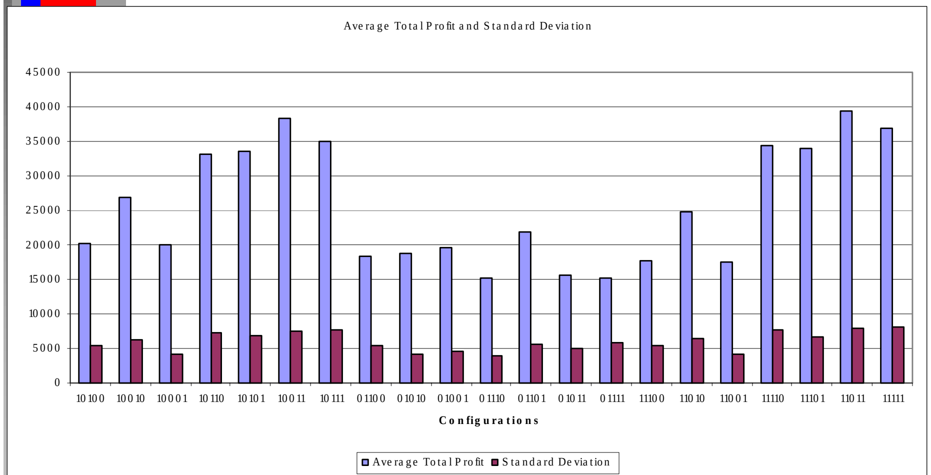
Comparison of Configurations

Configuration	10100	10010	10001	10110	10101	10011	10111
Average	20200.61	26887.64	19912.91	33048.56	33509.2	38336.57	34913.74
Std. Deviation	5488.322	6315.658	4200.408	7284.874	6782.751	7568.814	7768.177

Configuration	01100	01010	01001	01110	01101	01011	01111
Average	18389.98	18810.25	19684.06	15275.46	21807.7	15635.55	15220.35
Std. Deviation	5455.999	4250.08	4565.013	4000.774	5672.485	4958.555	5834.907

Configuration	11100	11010	11001	11110	11101	11011	11111
Average	17615.72	24752.63	17460.13	34335.34	33966.09	39299.21	36824.35
Std. Deviation	5489.152	6426.096	4199.158	7745.726	6708.431	7880.515	8203.693

Comparison of Configurations Performance



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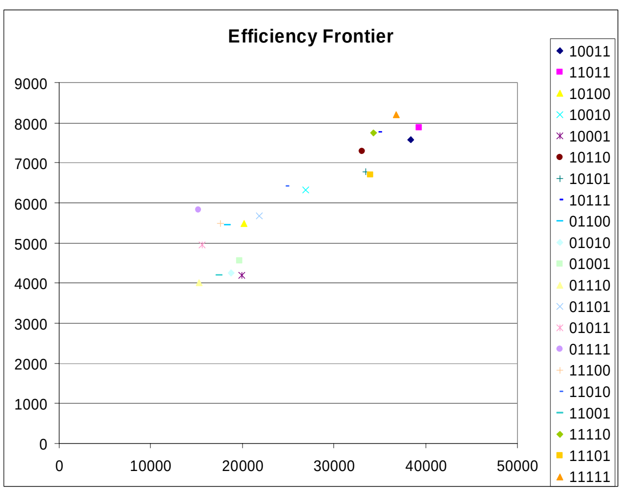
Efficiency Frontier of the Configurations



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Computational Results

- 100 replications sufficient to stabilize expected value and standard deviation per configuration
- Optimal design for average parameter values is clearly dominated
- 100 replications sufficient to find all "good" configurations

Increasing Variance of Parameters

- Increases variance of configuration performance
- Expected profit decreases
- More overlap of performance of configurations

Computational Experiment Conclusions

- Designing for average parameters yields a dominated configuration
- Parameter variance reduction improves configuration performance
- Significant computational burden (21,000 networks solved)

Conclusions

- Good definitions and measures for flexibility, robustness are lacking
- Current methodology is deterministic design and sensitivity analysis
- Hierarchical design algorithm performs well for small cases
- Computational issues for industrial cases

Supply Chain Modeling Challenges

- Multiple Periods
  - 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

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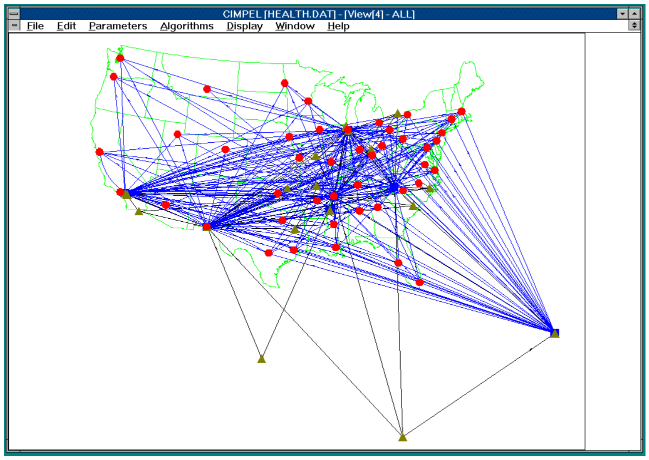
Supply Chain Design Challenges

- *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*

From a Multicommodity Case...



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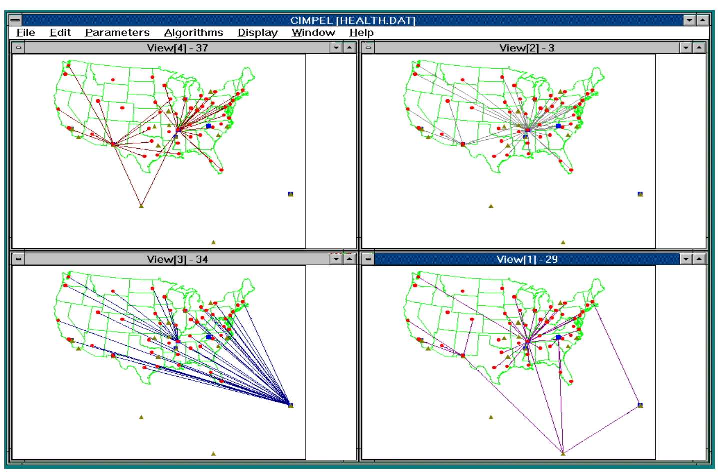
...and Configuration by a Current Design Tool



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To Design Tools for the Next Century

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