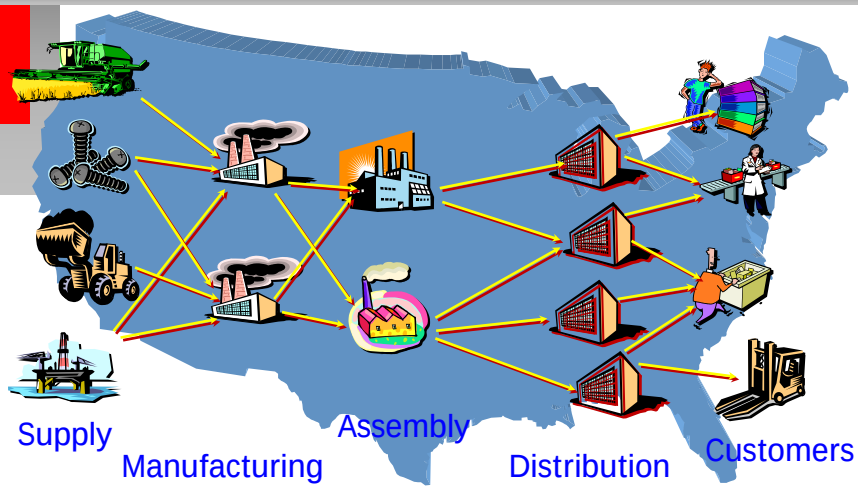
Strategic Design of Robust Global Supply Chains

M. Goetschalckx, S. Ahmed, A. Shapiro, T. Santoso, and G. Cordova

Georgia Institute of Technology
Tel. (404) 894-2317, fax (404) 894 2301
Email: marc.goetschalckx@isye.gatech.edu

Supply Chain



Supply Chains are Holistic

- *"Cradle to Grave", "Womb to Tomb"…*
- *Major Integrating Force*
  - *Internally between company subsidiaries, divisions, and departments*
  - *Externally between shippers, customers, service providers, …*
- *Complex Structure*
  - *Different owners, goals, reward structures*
  - *Costs of different types and scope*

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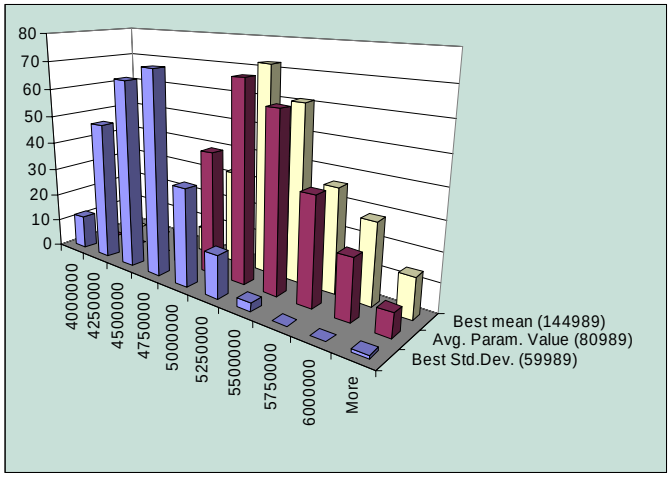
Supply Chains are Stochastic: Profits Have Distributions



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Strategic Planning Decisions

- *Strategic Decisions (configure)*
  - *Supply chain capital assets, capacity, and technology configuration*
  - *5 year schedule (planning horizon)*
- *Tactical Decisions (evaluate)*
  - *Production allocations and transportation flow quantities*
  - *Transfer prices*
  - *Yearly or seasonal flows*

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Strategic Supply Chain Design Model Characteristics

- *Multiperiod, multi-country, multicommodity (BOM), multi-echelon*
- *Capacitated components*
- *Global (duties, taxes, exchange rates)*
- *Strategic configuration (binary) and tactical master plan (continuous)*
- *Efficient (net cash flow) and robust (multiple scenarios)*

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Specialized Solution Algorithm

- *Very large Mixed-Integer Linear Program (MILP)*
- *Standard commercial solvers can only solve small to medium instances*
- *Solution with accelerated Benders decomposition*
  - *Run time of several hours on current PCs*

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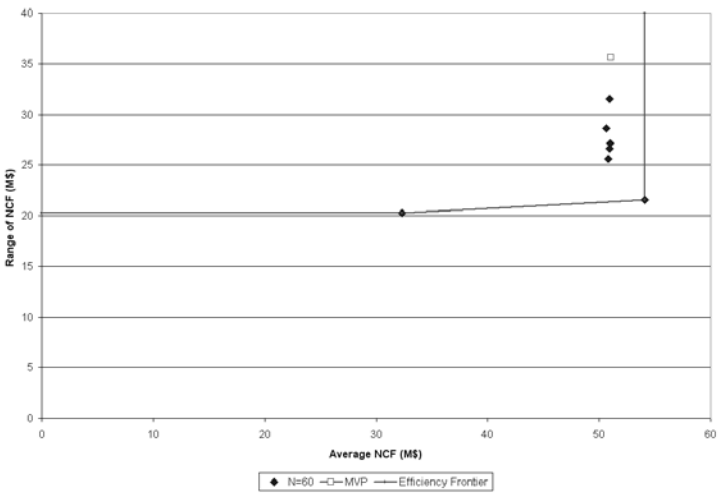
Paper Tissue in South America: Risk Analysis Graph



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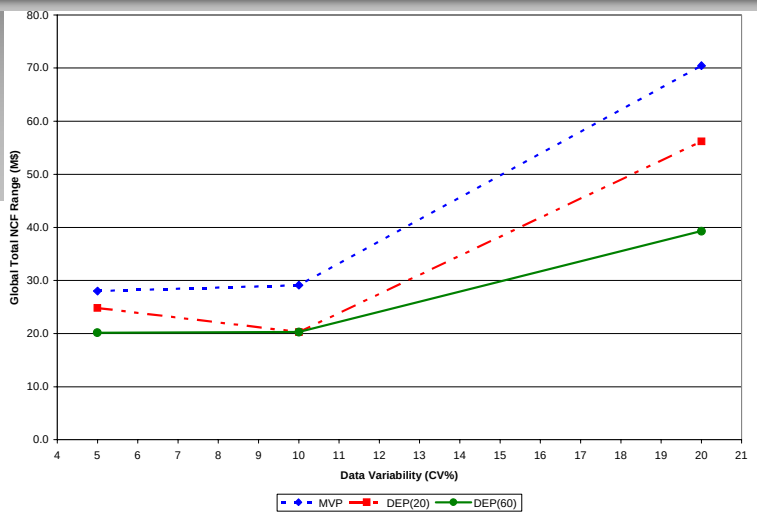
Paper Tissue in South America: Robustness of Solutions



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Paper Tissue in South America: Formulation Characteristics

Problem Statistics	N=1	N=10	N=20	N=60
Constraints	1,467	14,670	29,340	88,020
Inequality constraints	402	4,020	8,040	24,120
Equality constraints	1,065	10,650	21,300	63,900
Variables	6,894	68,310	136,550	409,510
Continuous variables	6,824	68,240	136,480	409,440
Binary variables	70	70	70	70

N = number of scenarios in master problem
400,000 variables in the master problem
72,000,000 variables optimized to identify robust stochastic solution

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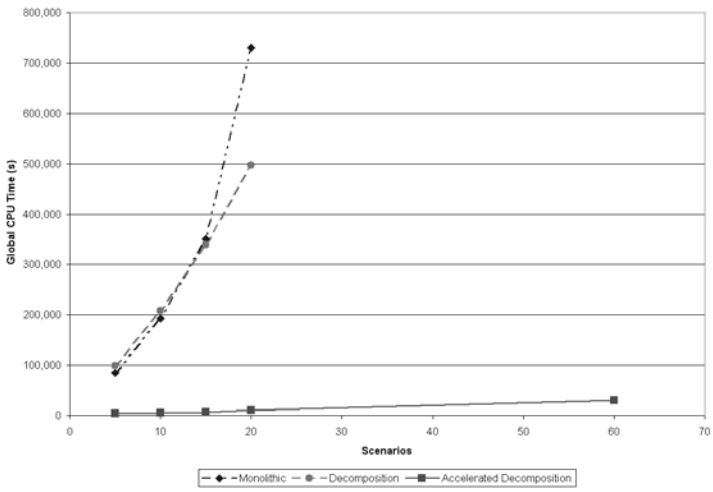
Paper Tissue in South America: Comparison of Run Times



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Acceleration Techniques

- *Preprocessing logistics constraints*
- *Trust region stabilization (1985)*
- *Linear relaxation bound (1977)*
- *Primal heuristics*
- *Warm start*
- *Knapsack lower bound constraints*
- *Disaggregation of Benders cuts (1988)*
- *Strengthening Benders cuts (1981)*

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Disaggregation of Cuts (A)

- Birge and Louveaux (1988) multi-cut
- Aggregate cut

$$Max \sum_j f_j y_j + \varphi$$

$$s.t. \quad \varphi \le \sum_j g_j\left(y_j \mid \mu_j\right)$$

- Disaggregate cuts

$$Max \sum_j f_j y_j + \sum_j \varphi_j$$

$$s.t. \quad \varphi_j \le g_j\left(y_j \mid \mu_j\right)$$

- N-1 more constraints per iteration, N-1 more continuous variables
- No weaker theoretically

Strengthening of Cuts (B)

- Magnanti and Wong (1981)
- Network flow sub problems are highly dual degenerate
  - Dual variables of closed facilities
  - Additional linear programming problem at a core point y^0

$$Min \quad g\left(\mu, y^0\right) \qquad Max \sum_j f_j y_j + \varphi$$

$$s.t. \quad g\left(\mu, y^k\right) = v\left(DSP_{y^k}\right) \qquad s.t. \quad \varphi \le g\left(y \mid \mu\right)$$

$$dual \quad feasibility$$

Primal Heuristics (C)

- *Two levels of primary binary variables:*
  - *Sites*
  - *Capacities (machines, technologies…)*
- *Fix sites, solve optimally for capacities*
- *MIP implemented, other heuristics are alternative algorithms*

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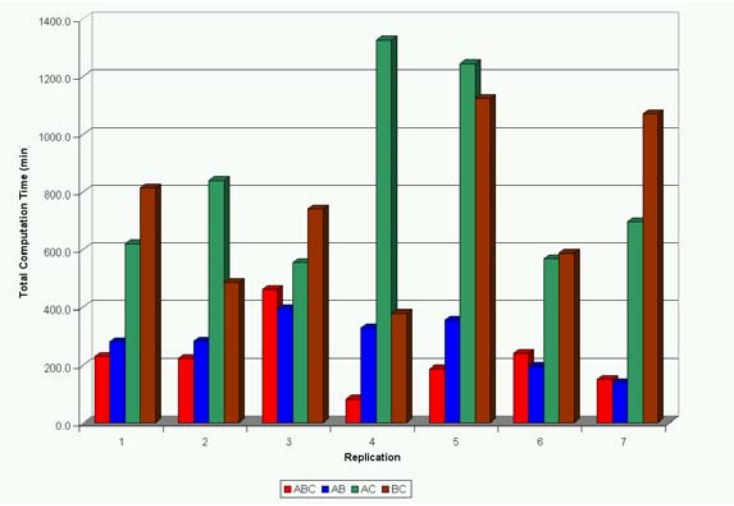
Computation Times by Replication



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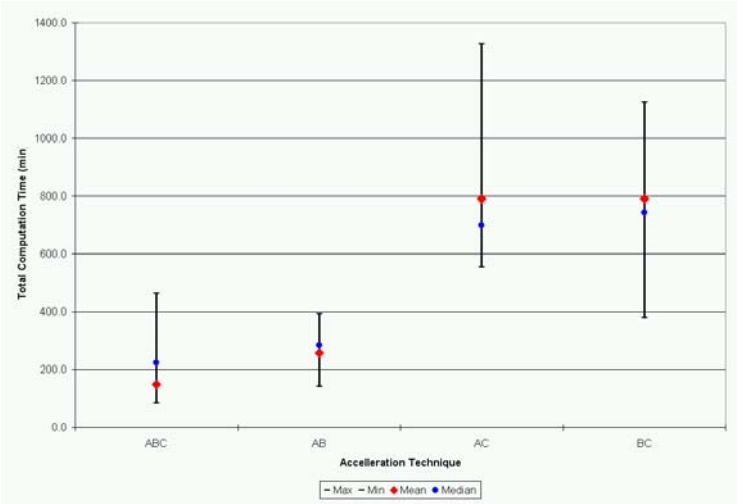
Box Plot of Computation Times



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Conclusions of Statistical Experiment

- *7 Replications gives 0.8 hours of resolution at 95 % confidence level*
- *24 Hour CPU cut-off time precludes evaluating individual techniques*
- *Strengthening and disaggregation of cuts combined is most efficient (contrast significant at 95 %)*
- *Primal heuristic least efficient (contrast not significant at 95 %)*

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