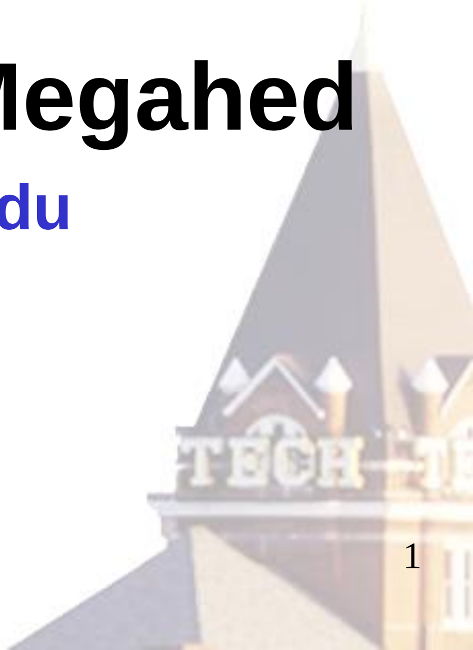
Procurement Planning with Supplier Uncertainty

Marc Goetschalckx and Aly Megahed

marc.goetschalckx@isye.gatech.edu

ISERC 2014 Montreal, Canada

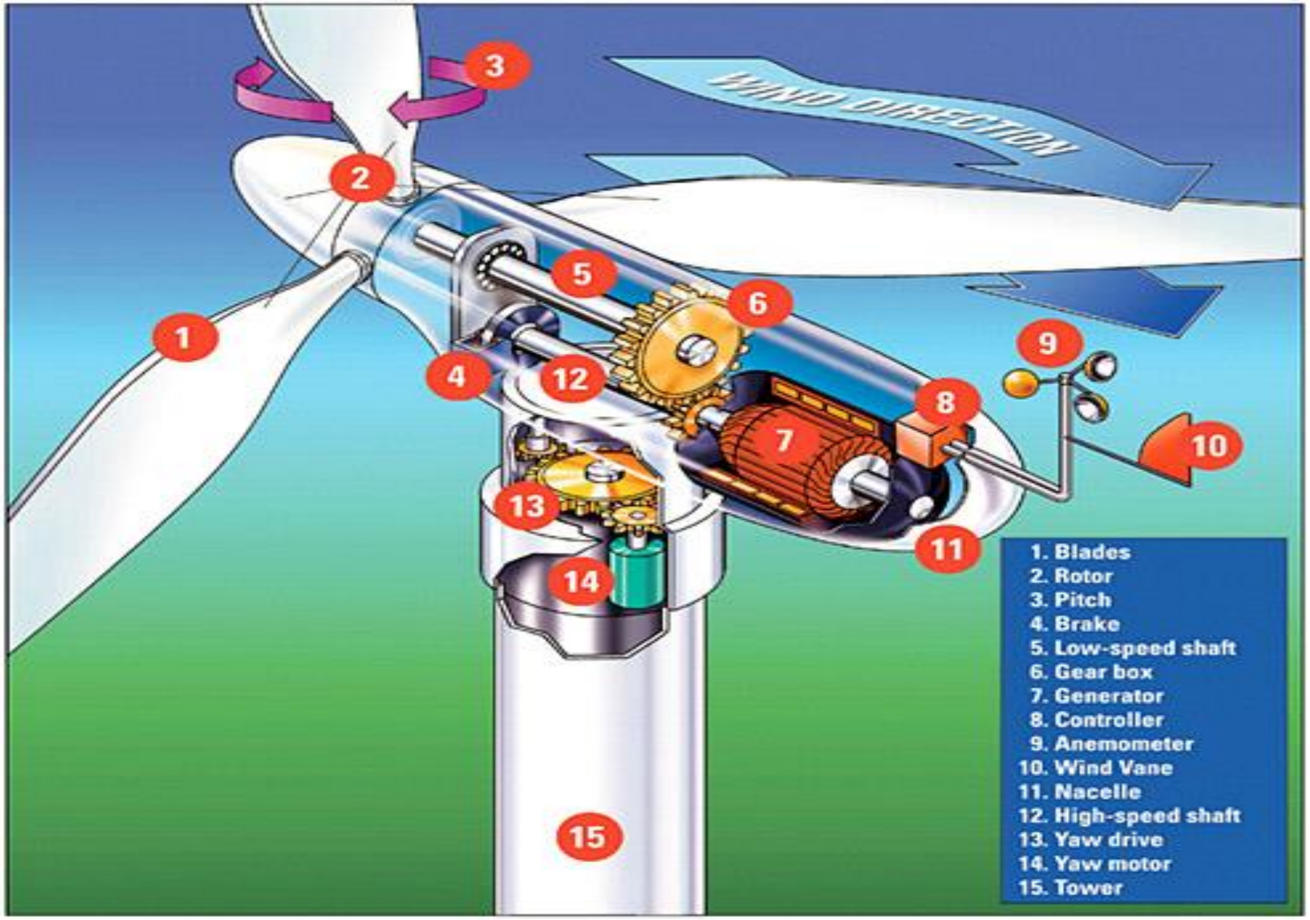
Georgia Institute of Technology
The H. Milton Stewart School of Industrial and Systems Engineering



Electrical wind turbine Farm in Ontario, CA

diameter
90 m (older) ~
120 m (current)
~ 160 m (future)
100 m tower
160 m tall

Wind Turbine Components



Components of a Wind Turbine (Liu and Chu 2012)

Wind Turbine Blades Transportation by Rail

(Source: www.vestas.com)

Georgia Institute of Technology
The H. Milton Stewart School of Industrial and Systems Engineering

Wind Turbine Components using Truck Transportation

(Source: www.nrel.gov)

Problem Characteristics

- **Problem is highly supply constrained**
  - ✓ Specialized suppliers with long lead times
  - ✓ Ordering from suppliers is done before uncertainty is revealed
  - ✓ After it is revealed, products flow, demand fulfilled
  - ✓ If supply < demand: backorders and lost sales
  - ✓ If supply > demand: inventory and capacity expansions
- **In wind turbines supply chains:**
  - ✓ Renting off-site storing for parts that arrived early
  - ✓ Arrangement for transportation

Supplier Uncertainty

- Suppliers' uncertainty
  - ✓ Demand uncertainty is most commonly studied
- Components of Uncertainty in supply/supplier are:
  - ✓ Uncertainty in costs and capacities (e.g. Alonso-Ayuso et al. 2003 & 2007, Santoso et al. 2005)
  - ✓ Random yield (e.g. Bollapragada and Morton 1999)
  - ✓ And/or random lead times (e.g. Dolgui et al. 2002)
- Uncertainty studied: random yield + stochastic lead times

Modeling General Supplier Uncertainty

- **For each supplier** $i \in S$, **product** $p \in P$ **in scenario** $\omega \in \Omega$, **Supplier uncertainty index** $\Delta_{iptt'}(\omega)$:
  - ✓% supplier delivers in period $t \in \{t', \ldots, |T|\}$ out of what he should have delivered in period $t' \in T$
  - ✓ $\sum_{t\in\{t',\ldots,|T|\}} \Delta_{iptt'}(\omega) \leq 1$.
  - ✓Supplier pays a penalty $ps_{iptt'}$ per unit delayed (backorder penalty may be a nonlinear function of the delay)

Model Development Highlights

Min $\sum_{i\in S}\sum_{j\in TF}\sum_{p\in P}\sum_{t\in T} pc_{ipt}.pq_{ijpt} + \mathbb{E}_{\omega}[Q(pq,\omega)]$

s.t. $\sum_{j\in TF} pq_{ijpt} \leq Max_{ipt} \quad \forall i\epsilon S, \forall p \in P, \forall t\epsilon T$

$pq_{ijpt} \geq 0 \quad \forall i\epsilon S, \forall j \in TF, \forall p \in P, \forall t\epsilon T$

$Q(pq,\omega)$ is the optimal value of the 2nd stage problem:

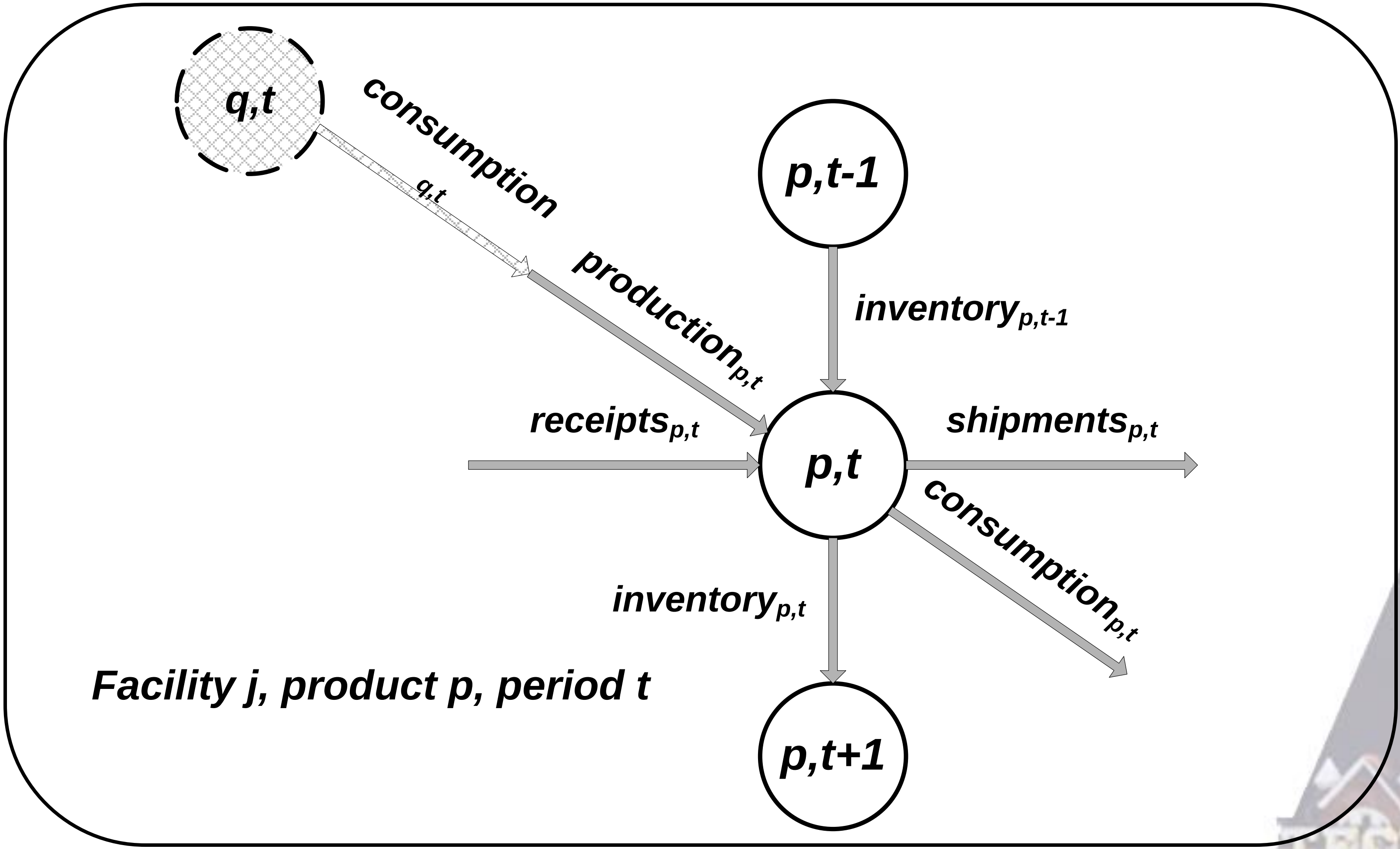
- Objective function: Transportation + (BOM Assembly) Transformation + Inventory + Backorder
  - ✓ + (Tactical) capacity expansion costs
  - ✓ - Supplier penalty
  - ✓ + Lost sales penalty

Model Development Highlights (Continued)

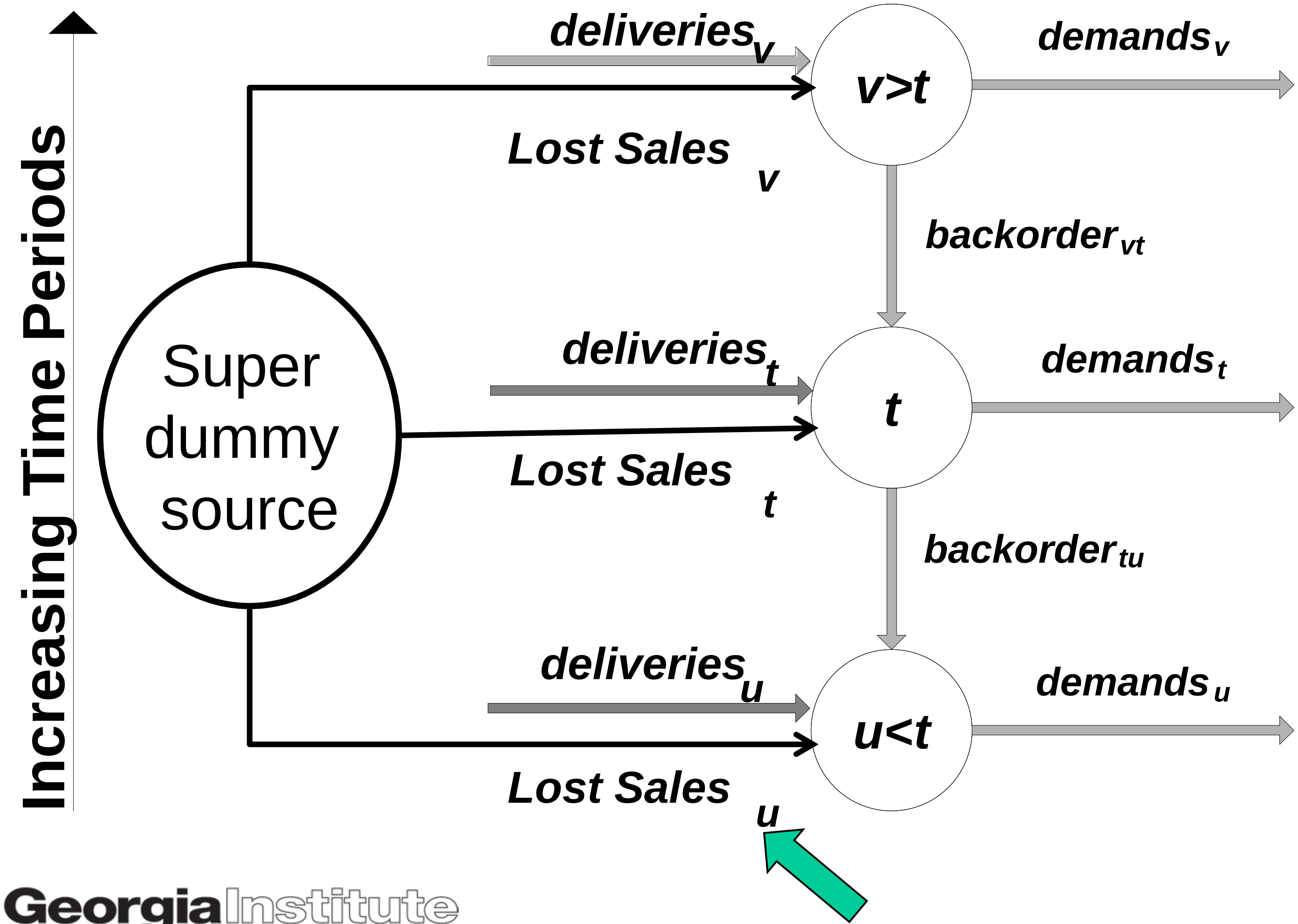
- **Second Stage constraints**:
  - ✓ Flow Balance using BOM
  - ✓ $x_{ijpt}(\omega) = \sum_{t' \epsilon \{1,\cdots,t\}} \Delta_{iptt'}(\omega) \,.\, pq_{ijpt'} \quad \forall i \epsilon S, \forall j \epsilon TF, \forall p \epsilon P, \forall t \epsilon T$
  - ✓ Capacity constraints with added tactical capacity expansions at suppliers, transportation, inventory, production, throughput, and resources, e.g.

$$iq_{jpt}(\omega) \leq icap_{jpt} + icapExp_{jpt}(\omega) \quad \forall j \epsilon TF, \forall p \epsilon P, \forall t \epsilon T$$

Model Development: Transformation Facilities Conservation of Flow



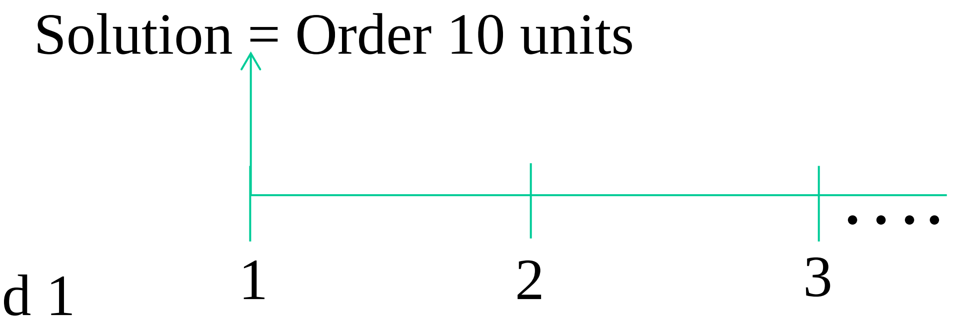
Customers Conservation of Flow with Backorders



Relatively Complete Recourse

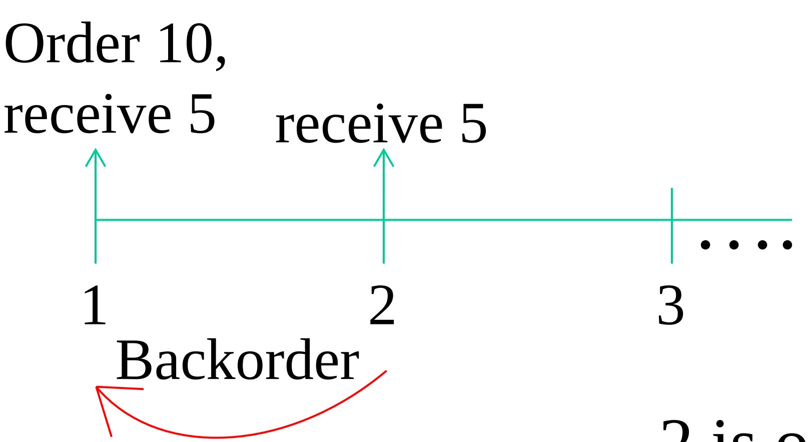
Optimal Solution May Order More than the Deterministic Demand

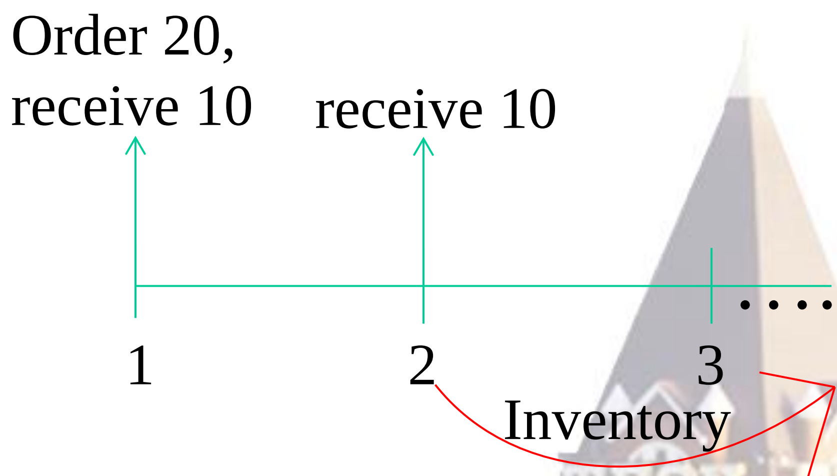
Deterministic Problem
Optimal Solution



Demand = 10 units at period 1

Expected Value or One-Scenario Problem





2 is optimal if purchasing + inventory < backorder

Numerical Experiment Setup

- **24 Suppliers with three levels of reliability**
  - ✓2,5,8 maximum delay time
  - ✓Quantity delivered in each period binomially distributed with probability linear in function of scenarios
  - ✓3 levels purchasing cost dependent on reliability (1:0.7:0.4 cost ratios)
- **2 levels backordering costs**
- **52 periods + 5 periods with zero demand**

Numerical Experiment Setup (Continued)

- **50 Scenarios**

Numerical Experiment Execution

- **Database: Microsoft Access**
  Model: GPML
  MIP Solver: CPLEX 12.2
  Computer: T7200, 6 MB RAM
- **Deterministic Equivalent Problem (DEP) with default parameters (no decomposition)**
  - ✓LP Model generation 25 minutes
  - ✓Model solution < 0.2 minutes

Results of Numerical Experiment: Sourcing from Unreliable Suppliers

Backorder Cost Level	Purchasing Cost Level	Cost Increase over 100% Reliable	% Procurement Most Reliable	% Procurement Medium Reliable	% Procurement Least Reliable	% Procurement over Demand
Low	Low and Equal for All Suppliers	1.51	62.34	11.08	26.58	0
High	Low and Equal for All Suppliers	3.12	69.71	13.13	17.16	0.09
Low	High and Equal for All Suppliers	0.09	44.67	18.48	36.85	0
High	High and Equal for All Suppliers	0.27	50.99	20.03	28.98	0
Low	High with More Reliable Suppliers Being More Expensive	0.62	0	0	100	0
High	High with More Reliable Suppliers Being More Expensive	4.15	0	1.94	98.06	0.45
Low	Low with More Reliable Suppliers Being More Expensive	9.72	0	2.01	97.99	0
High	Low with More Reliable Suppliers Being More Expensive	20.79	2.1	1.83	96.06	3.71

Results of Numerical Experiment

Backorder Cost Level	Purchasing Cost Level	% Procurement Most Reliable	% Procurement Medium Reliable	% Procurement Least Reliable	% Procurement over Demand	% Cost EVP below MVP
Low	Low and Equal for All Suppliers	51.38	9.99	38.63	0	1.44
High	Low and Equal for All Suppliers	52.87	10.54	36.59	0.26	2.57
Low	High and Equal for All Suppliers	41.83	16.85	41.32	0	0.09
High	High and Equal for All Suppliers	41.38	17.17	41.44	0	0.19
Low	High with More Reliable Suppliers Being More Expensive	0	0	100	0	0.6
High	High with More Reliable Suppliers Being More Expensive	0	0	100	0.04	3.92
Low	Low with More Reliable Suppliers Being More Expensive	0	0	100	0	9.5
High	Low with More Reliable Suppliers Being More Expensive	0	0.03	99.97	0.69	19.55

EVP: expected value problem (stochastic)

MVP: mean value problem (deterministic)

Results of Numerical Experiment

- **Cheapest suppliers are selected regardless of reliability**
- **Expected Value Problem cost more than deterministic problem (100% reliable)**
- **Excess purchasing only for large backorder cost and small purchasing cost**
- **Cost increase EVP over deterministic (100% reliable) grows with backorder cost**

Results of Numerical Experiment (Continued)

- **% cost decrease of EVP versus MVP (VSS) increases with backorder costs**
- **Decisions of the model cannot be predicted by "intuition" or rules of thumb, a mathematical modes is required**
  - ✓ Procurement source and quantity and timing (purchase + transport cost), inventory, backorder, and excess procurement are extremely interdependent

Conclusions

- ***A 2-stage stochastic programming model for comprehensive tactical supply chain planning under supplier uncertainty was developed***
- ***Uncertainty/unreliability of suppliers in one of its most general forms is modeled***
- ***A direct real-world application is in the wind turbines industry***
- ***Optimal procurement quantities when considering supplier uncertainty might be larger than deterministic demand***

Conclusions (Continued)

- ***Model chooses cheapest suppliers, regardless of their reliability***
- ***Solution of Expected/mean value problem > deterministic problem***
- ***% relative difference in costs increases when backorder costs get higher***
- ***VSS/stochastic solution reached values of up to 20%***

May I answer any questions?