Enhancing decision making process in a cooperative and competitive environment

Enterprise-Wide Optimization Seminar
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Motivation

Current economic crisis

New market trends
- Market globalization
- Market structure
- Outsourcing

New challenges for PSE community
- Higher competition
- Reduce inventories and subcontracting
- Higher quality requirements
- Interaction among 3rd Parties (several SCs)

GOAL
Enhance the SC competitiveness

Enhancing decision making process in a cooperative and competitive environment
Introduction

The Supply Chain (SC) is a network of facilities and distribution Options, that develops the functions of:

- Acquisition of raw material (RM).
- RM's transformation in intermediate and final products.
- The distribution of product finished to the final consumers.

Supply chain management (SCM)

Strategic decisions: design the SC network by determining the optimal location of production plants, warehouses, supplier and raw material selection, the production technologies and equipment capacities to be installed in order to fulfill the market demands.

Laínez et al. (2007); Cakravastia, Toha and Nakamura (2002); Bansal, Karimi and Srinvasan (2008); Laínez (2010).
The Supply Chain (SC) is a network of facilities and distribution Options, that develops the functions of:

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- The distribution of product finished to the final consumers.

Supply chain management (SCM)

Tactical decisions: the optimal production, distribution, inventory and subcontracting levels must be determined considering a fixed SC network configuration.

Enhancing decision making process in a cooperative and competitive environment

Introduction

The Supply Chain (SC) is a network of facilities and distribution Options, that develops the functions of:

- Acquisition of raw material (RM).
- RM's transformation in intermediate and final products.
- The distribution of product finished to the final consumers.

Supply chain management (SCM)

Operational decisions: allocates production orders, sequencing and timing of the tasks.

Enhancing decision making process in a cooperative and competitive environment
Outline

- Motivation
- Introduction
- Open issues and Goals
- Cooperative and competitive analysis
  - Tactical decision level
  - Tactical-operational
  - Uncertainty Management
  - Robust DM tools
- Conclusions

Enhancing decision making process in a cooperative and competitive environment
Open issues

DM under uncertainty:

- Availability of production resources
- Raw materials supply
- Operating parameters (lead times, transport times, etc.)
- Market scenario (demand, prices, delivery requirements, etc.)

Tools:

- **Model Predictive Control** (Bose and Penky, 2000),
- **Multi-Parametric Programming** (Wellons and Reklaitis, 1989; Dua *et al.*, 2009)
- **Fuzzy Linear Programming** (Peidro *et al.*, 2010)
- **Stochastic Programming** (Gupta and Maranas, 2003; You and Grossmann, 2010; Amaro and Barbosa-Póvoa, 2009; Baghalian, 2013; Klibi and Martel, 2012).

Enhancing decision making process in a cooperative and competitive environment
Open issues

DM under uncertainty:
- Availability of production resources
- Raw materials supply
- Operating parameters (lead times, transport times, etc.)
- Market scenario (demand, prices, delivery requirements, etc.)

Proposed approaches
- Extend the scope of the SCM approaches under uncertainty
  - Competitors Behavior
  - Developing Reactive and Proactive approaches
Open Issues

- Role of the competitors
  - Cooperative and competitive scenarios
- Cooperative
  - Vertical integration
  - Buyer and seller negotiation lead to discounts in the contracts. Kohli and Park (1989)

Competitive

- Game Theory.
  - Leng and Zhu, 2009; Wang, 2006
- Seller and buyer
  - Cachon, 2004; Granot and Yin, 2008;
    - fix the price between seller and buyer.

Proposed approach

- Explicitly consider the presence of other SCs
  - Under cooperation
  - or fair competition for the global demand
Multi-Objective Optimization:

- Looking for the **tradeoff** among several objectives (internal or external):
  - **Economic** (total cost, profit, NPV, et.) vs:
    - Environmental impact
    - Risk (inversion)
    - ...
- Guillén *et al.*, 2005; Bojarski *et al.*, 2009; Guillén and Grossmann, 2010; Lin *et al.*, 2012

SC industrial problems:

- Chemical (Rodera *et al.*, 2002; Sabio *et al.*, 2011)
- Pharmaceutical (Nicolotti *et al.*, 2011)
- Petrochemical (Zhong and You, 2011)
- Food (Mele *et al.*, 2011)
- Automotive industries (Cook *et al.*, 2007)

**Proposed approach**

- Take into account **Objectives** from different entities
  - SC producers (economic)
  - Customers (Delivery time, quality, etc.)

Enhancing decision making process in a cooperative and competitive environment
Motivation

- Usual SCM approach
  - Single SC view

Role of competitors?
- Model for competitors?
  - Uncertain competition behavior

Game theory (GT)

• GT provides solutions simulating the **interactions between**:
  – Set of players \((i=1,...,I)\)
  – Set of strategies \((S_{i,n}; i=1,...,I; n=1,..,N)\)
  – Set of payments \((P_{i,n}; i=1,..,I; n=1,..,N)\)

• Cooperative and **non-cooperative games**

• Payoff Matrix

• Nash Equilibrium
  – If each **player has chosen** a strategy and any player can obtain a benefit by changing his or her strategy while the other players keep theirs unchanged

Industrial organizations (micro economics)

• Problem: Cournot oligopoly
  – Same product (competitive demand), estimate offer, and they maximize their profit.

• Problem: Bertrand oligopoly
  – Prices war, looking for the capture of demand by offering the lowest prices.
Main Goal

- Optimize the planning of supply chains for decision making in cooperative and/or competitive scenarios.
Problem statement

Given:
i = Plants (storage is allowed)
n = Product
h = Time
j = Markets
s = Supply Chains

Decision Variables:
- Distribution $T(i,n,h,j)$
- Production $Q(i,n,h)$
- Inventory $W(i,n,h)$
- Backorder $E(i,n,h)$

Objective 1 (Cooperative scenario):
$$\text{Minimize } z1(g) = \sum_{i \in I} \sum_{n} \sum_{h} a_{in} Q_{inh}(1 + e_{b})^h + \sum_{i \in I} \sum_{n} \sum_{h} c_{in} W_{inh}(1 + e_{b})^h$$
$$+ \sum_{i \in I} \sum_{n} \sum_{h} d_{in} E_{inh}(1 + e_{b})^h$$

Objective 2 (Non-cooperative scenario):
$$\text{Minimize } CST(g) = \sum_{i \in I} \sum_{n} \sum_{h} \sum_{j} P_{s_{ijn}} T_{inhj} Prate_{e_g} + z1$$

Open Issues:
- Vertical integration
- Uncertainty Management
- Market globalization (third parties)
- Multi-objective analysis

Objectives:
- All SC’s work to Minimize total cost ($z1$)
- Minimize the expenses of the buyers ($CST$)

Enhancing decision making process in a cooperative and competitive environment
Problem statement

Given:
- \( i \) = Plants (storage is allowed)
- \( n \) = Product
- \( h \) = Time
- \( j \) = Markets
- \( s \) = Supply Chains

Decision Variables
- Distribution \( T(i,n,h,j) \)
- Production \( Q(i,n,h) \)
- Inventory \( W(i,n,h) \)
- Backorder \( E(i,n,h) \)

Objectives
- Minimize total cost \((z1)\)
- Minimize the expenses of the buyers \((\text{CST})\)

Cooperative scenarios:

\[
\min z1(g) = \sum_{i \in I} \sum_{n} \sum_{h} a_{in} Q_{inh} (1 + e_{h})^h + \sum_{i \in I} \sum_{n} \sum_{h} c_{in} W_{inh} (1 + e_{h})^h + \sum_{i \in I} \sum_{n} \sum_{h} d_{in} E_{inh} (1 + e_{h})^h + \sum_{i \in I} \sum_{n} \sum_{h} \sum_{j} k_{ijn} T_{ijn} (1 + e_{h})^h
\]

Non cooperative scenarios between SC’s:

\[
\min \text{CST}(g) = \sum_{i \in I} \sum_{n} \sum_{h} \sum_{j} P_{ijn} T_{ijn} \text{Prate}_{g} z1
\]

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Discounts \((\text{Prate}_{g})\)
Liang 2008

\[ \text{Min } z_2(g) = \sum_{i \in I_2} \sum_{n} \sum_{h} \sum_{j} \left[ \frac{u_{inj}}{s_{inhj}} \right] T_{inhj} \]

- Delivery Time

- Constraints:
  - Material balance
  - Shipments balance
  - Production levels
  - Demand satisfaction
  - Storage limits
  - Budget capacity

\[ II_{in1} W_{inh-1} + E_{inh-1} + Q_{inh} - T_{inhj} = W_{inh} - E_{inh} \quad \forall i, n, h \]

\[ II_{in1} + W_{inh-1} - E_{inh-1} + Q_{inh} \geq \sum_j T_{inhj} \quad \forall i, n, h \]

\[ \sum_{n=1}^N l_{in}Q_{inh} \leq F_{ih} \quad \forall i, h \]

\[ \sum_{n=1}^N r_{in}Q_{inh} \leq M_{ih} \quad \forall i, h \]

\[ \sum_i T_{inhj} \geq D_{inh} \quad \forall n, h, j \]

\[ \sum_i \sum_n v_n T_{inhj} \leq R_{ddhj} \quad \forall h, j \]

\[ z_1(g) \leq B_{dd}(g) \quad \forall g \]

Enhancing decision making process in a cooperative and competitive environment
Case study

- 2 Supply Chains
  - Plant 1 and 2 – SC1
  - Plant 3 and 4 – SC2
- 4 Distribution centers (intermediate consumers).
- 2 Products (Plant 1 – Plant 4).
- Time horizon of 3 months.
- Other data:

<table>
<thead>
<tr>
<th>Source</th>
<th>Product</th>
<th>a&lt;i,n&gt;</th>
<th>c&lt;i,n&gt;</th>
<th>d&lt;i,n&gt;</th>
<th>l&lt;i,n&gt;</th>
<th>r&lt;i,n&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant1</td>
<td>P1</td>
<td>20</td>
<td>0.3</td>
<td>32</td>
<td>0.05</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>P2</td>
<td>10</td>
<td>0.15</td>
<td>18</td>
<td>0.07</td>
<td>0.08</td>
</tr>
<tr>
<td>Plant2</td>
<td>P1</td>
<td>20</td>
<td>0.28</td>
<td>20</td>
<td>0.04</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>P2</td>
<td>10</td>
<td>0.14</td>
<td>16</td>
<td>0.06</td>
<td>0.07</td>
</tr>
<tr>
<td>Plant3</td>
<td>P1</td>
<td>20</td>
<td>0.3</td>
<td>32</td>
<td>0.05</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>P2</td>
<td>10</td>
<td>0.15</td>
<td>18</td>
<td>0.07</td>
<td>0.08</td>
</tr>
<tr>
<td>Plant4</td>
<td>P1</td>
<td>20</td>
<td>0.28</td>
<td>20</td>
<td>0.04</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>P2</td>
<td>10</td>
<td>0.14</td>
<td>16</td>
<td>0.06</td>
<td>0.07</td>
</tr>
</tbody>
</table>

Liang (2005).
Liang (2008).

- Strategic
- Tactical
- Operational

Vertical integration
Uncertainty Management
Market globalization (third parties)
Multi-objective analysis

Enhancing decision making process in a cooperative and competitive environment
% **Discount** in the price

- 5 **strategies** each player (SC)

<table>
<thead>
<tr>
<th>SC2 (B)</th>
<th>0.0%</th>
<th>0.1%</th>
<th>0.2%</th>
<th>0.3%</th>
<th>0.4%</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC1 (A)</td>
<td>0.0%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(A,B)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.1%</td>
<td>(A,B)</td>
<td>(A,B)</td>
<td>(A,B)</td>
<td>(A,B)</td>
<td>(A,B)</td>
</tr>
<tr>
<td>0.2%</td>
<td>(A,B)</td>
<td>(A,B)</td>
<td>(A,B)</td>
<td>(A,B)</td>
<td>(A,B)</td>
</tr>
<tr>
<td>0.3%</td>
<td>(A,B)</td>
<td>(A,B)</td>
<td>(A,B)</td>
<td>(A,B)</td>
<td>(A,B)</td>
</tr>
<tr>
<td>0.4%</td>
<td>(A,B)</td>
<td>(A,B)</td>
<td>(A,B)</td>
<td>(A,B)</td>
<td>(A,B)</td>
</tr>
</tbody>
</table>
Law of Demand elasticity

• Elasticity demand price that measures the sensitivity of quantity demanded to prices changes, Is given by:

\[ Ep = \frac{\Delta X Q}{\Delta P^0P} \]

• \( Ep \) is the elasticity demand price: = -4.9

<table>
<thead>
<tr>
<th>Price</th>
<th>Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>1000.05</td>
</tr>
<tr>
<td>99.999</td>
<td>1000.10</td>
</tr>
<tr>
<td>99.998</td>
<td>1000.15</td>
</tr>
<tr>
<td>99.997</td>
<td>1000.20</td>
</tr>
</tbody>
</table>

Enhancing decision making process in a cooperative and competitive environment
### Results

<table>
<thead>
<tr>
<th></th>
<th>SC1 standalone</th>
<th>SC2 standalone</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Objective Function</strong></td>
<td>min ( z_1 )</td>
<td>min ( z_1 )</td>
</tr>
<tr>
<td><strong>Total Cost (( z_1 ), $)</strong></td>
<td>838 212</td>
<td>840 904</td>
</tr>
<tr>
<td><strong>Delivery time (( z_2 ), h)</strong></td>
<td>1681</td>
<td>1747</td>
</tr>
<tr>
<td><strong>Profit ($)</strong></td>
<td>3 665 787</td>
<td>3 663 095</td>
</tr>
<tr>
<td><strong>Expenses of the buyers (CST, $)</strong></td>
<td>5 342 213</td>
<td>5 344 904</td>
</tr>
</tbody>
</table>

**Enhancing decision making process in a cooperative and competitive environment**
Cooperative and Competitive.

Cooperative
• Best for Enterprises

Competitive
• Best for SC1 and Buyers
Enhancing decision making process in a cooperative and competitive environment
Economic analysis

Cost Distribution (Cost, $)

- **Standalone solutions**
  - Cost reduction
    - SC1 (standalone) $2692 \ ($ < 1\%$)
    - Cooperation SC1+SC2 $4.2\%$

**Cooperative Scenario**

Enhancing decision making process in a cooperative and competitive environment
Economic analysis

**Cost reduction**

- SC1 (standalone) $2692 ( < 1 %)
- Cooperation SC1+SC2 $4.2%

**Competitive Solutions!!**

Enhancing decision making process in a cooperative and competitive environment
In order to exploit the flexibility of the proposed approach, **bargaining tools** must be studied.
Conclusions

• This work extends the use of GT as decision technique to determine the optimal SC production, inventory and distributions levels in a competitive planning scenario.

• New control parameter (discount prices) in order to cooperate or compete.

• GT has been used as a Reactive approach to manage the uncertainty.
Objective

- Show the *Applicability* of the proposed approach
- New parameter to manage the competitor behavior
  - Product Quality
- Introduce Product Quality Assessment in SC formulation

Previous work

- Single approach

Cooperative and competitive SC scheduling

Strategic (Design)
Tactical (Planning)
Operational (Scheduling)

Enhancing decision making process in a cooperative and competitive environment

Proposed framework

SC Scheduling

- Scheduling
  - Allocation of the resources, equipment availability, etc.

- Distribution
  - Send products from production plants to final consumers

Game Theory

Uncertainties

- Competition behavior
- Product quality

Total Quality Control

- Quality evaluation costs
- Defective products
- Storage and delivery

- Product quality
- Production quality

Supply Chain Network

- Competition behavior
- Product price $F(\text{Quality})$

| SC2 (B) | Medium | High |
| SC1 (A) |        |      |
| Medium  | (A, B)  | (A,B) |
| High    | (A,B)   | (A,B) |

Enhancing decision making process in a cooperative and competitive environment
Problem statement

- Decision Variables
  - $B(c, i, j, t)$: Quantity of material produced
  - $W(c, i, j, t)$: 1 if unit $j$ produce task $i$ of SC $c$ at time $t$; 0, otherwise
  - $S(c, s, t)$: Quantity of material stored
  - $Rm(c, s, t)$: Quantity of raw material purchased at time $t$

Constraints

- Assignment
  \[
  \sum_i \sum_t W(c, i, j, t) - 1 \leq M \cdot (1 - W(c, i, j, t)), \quad \forall c, i, j, t
  \]
- Production Capacity
  \[
  W(c, i, j, t) \cdot V_{ij}^{\text{min}} \leq B(c, i, j, t) \leq W(c, i, j, t) \cdot V_{ij}^{\text{max}}, \quad \forall i, j \in K, t
  \]
- Storage
  \[
  0 \leq S(c, s, t) \leq C_s \quad \forall c, s, t
  \]
- Demand Satisfaction
  \[
  \sum_c S(c, s, t) = Dem(s) \quad \forall s \in Cos, t = T
  \]
- Material Balances
  \[
  S(c, s, t) = S(c, s, t-1) + \sum_{i \in Tis} \alpha_{is} \cdot \sum_{j \in K} B(c, i, j, t-\delta) - \sum_{i \in Tis} \alpha_{is} \cdot \sum_{j \in K} B(c, i, j, t) + Rm(c, s, t) \quad \forall s, t
  \]
- Transport cost
  \[
  CTr_c = \sum_{s \in Cos} S(c, s, t) \cdot Tcost_s \quad \forall c
  \]
Quality costs

- Check product quality
  \[ QPV_c = \sum_{i}^{l} \left( T \sum_{t}^{T} B_{c,i,j,t} \right) Q_{1,q} \quad \forall c \]

- Evaluation of raw material quality (reception and inventory)
  \[ QV_{c,s} = \sum_{t}^{T} Rm_{c,t} Q_{1,q} + \sum_{t}^{T} S_{c,s,t} Q_{2,q} \quad \forall c,s \in \left( \neq fp, RM \right) \]

- Defective product cost
  \[ CDP_c = \sum_{s \in Cos_s} S_{c,s,t} T_s \quad \forall c \quad Ts = 1-Q1q \]

- Total Cost
  \[ C_{tot_c} = QVT_c + QPV_c + CTr_c + CDP_c \quad \forall c \]

- Price of products
  \[ Price_{c,s} = v_s + Y_q \quad \forall c,s \in Fp \]

- Benefit
  \[ Benefit_c = \sum_{s \in Fp} Price_{c,s} \quad \forall c \]

**Competition behavior**

<table>
<thead>
<tr>
<th>SC2 (B)</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC1 (A)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium</td>
<td>SC1(Q1, Yq, Q2)</td>
<td>SC1(Q1, Y, Q2)</td>
</tr>
<tr>
<td></td>
<td>SC2(Q1, Yq, Q2)</td>
<td>SC2(Q1, Y, Q2)</td>
</tr>
<tr>
<td>High</td>
<td>SC1(Q1, Y, Q2)</td>
<td>SC1(Q1, Y, Q2)</td>
</tr>
<tr>
<td></td>
<td>SC2(Q1, Y, Q2)</td>
<td>SC2(Q1, Y, Q2)</td>
</tr>
</tbody>
</table>
Case study

- 2 Supply Chains
  - Plant 1; Market 1-4
  - Plant 2; Market 1-4
- Production recipe: Kondili et al. (1993)

- Time horizon (14 h)
- Demand

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Q1</th>
<th>Q2</th>
<th>Yq</th>
</tr>
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<tbody>
<tr>
<td>Medium</td>
<td>0.97</td>
<td>0.97</td>
<td>0</td>
</tr>
<tr>
<td>High</td>
<td>1.0</td>
<td>1.0</td>
<td>1</td>
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</table>
Cooperative results

Production/distribution schedule

<table>
<thead>
<tr>
<th>Quality</th>
<th>High</th>
</tr>
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<tbody>
<tr>
<td>SC1</td>
<td></td>
</tr>
<tr>
<td><strong>Heater</strong></td>
<td></td>
</tr>
<tr>
<td>Reactor 1</td>
<td>80</td>
</tr>
<tr>
<td>Reactor 2</td>
<td>72</td>
</tr>
<tr>
<td>Still</td>
<td>40</td>
</tr>
<tr>
<td>Trans1</td>
<td>80</td>
</tr>
<tr>
<td>Trans2</td>
<td>9</td>
</tr>
<tr>
<td><strong>Raw Materials</strong></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>80</td>
</tr>
<tr>
<td>B</td>
<td>60</td>
</tr>
<tr>
<td>C</td>
<td>92</td>
</tr>
</tbody>
</table>

| SC2     |      |
| **Heater** |      |
| Reactor 1 | 80 |
| Reactor 2 | 80 |
| Still    | 40 |
| Trans3   | 80 |
| Trans4   | 9  |
| **Raw Materials** | | |
| A        | 80 |
| B        | 60 |
| C        | 92 |

<table>
<thead>
<tr>
<th>Task</th>
<th>Heat</th>
<th>Reaction 1</th>
<th>Reaction 2</th>
<th>Reaction 3</th>
<th>Separation</th>
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<tr>
<td>Time</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Market 1</th>
<th>Market 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prod 1</td>
<td>Prod 2</td>
</tr>
<tr>
<td>Prod 1</td>
<td>Prod 2</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

Enhancing decision making process in a cooperative and competitive environment
Conclusions

- This work extends the use of GT as decision technique to determine the optimal SC assignment, timing, and distribution in competitive/cooperative scenarios.

- New control parameter (product quality) in order to cooperate or compete.

- Total Quality Control (TQC) in SCM models.
Summary

• Competitors behavior
  – Discount prices

• Competitors behavior
  – Product Quality Level

SC scheduling cooperative and competitive scenarios

SC planning cooperative and competitive scenarios

SC Planning reactive approach and Multi objective analysis

Enhancing decision making process in a cooperative and competitive environment
Outline

- Motivation
- Introduction
- State of the art
- Open issues and Goals
- Cooperative and competitive analysis
- Tactical decision level
  - Tactical-operational
  - Uncertainty Management
  - Robust DM tools
- Conclusions

<table>
<thead>
<tr>
<th>SC1 (A)</th>
<th>SC2 (B)</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SC1(Q1, Yq, Q2)</td>
<td></td>
<td>SC1(Q1, Y, Q2)</td>
</tr>
<tr>
<td></td>
<td>SC2(Q1, Yq, Q2)</td>
<td></td>
<td>SC2(Q1, Y, Q2)</td>
</tr>
</tbody>
</table>

- Reactive approaches
  - MPC
  - Parametric programming
  - Multiparametric programming
  - Game Theory optimisation

- Preventive approaches
  - Fuzzy linear programming
  - Two Stage Stochastic programming
  - Multi Stage Stochastic programming

Enhancing decision making process in a cooperative and competitive environment
Decision making under uncertainty

- The necessity to consider uncertainty → functionality of planning models
  - which is to allocate resources for the future based on current information and future projections.

Production ≥ demand
Demand = ?
If demand = ?
  Then Inventory ?
  And Distribution ?
end
Objective

• Introduce the competition behavior of several supply chains as a new source of uncertainty.

  – Production planning under demand uncertainty. (cooperative scenario)
    • Two stage stochastic programming (2SLPwR-MILP)
    • Production (First stage variable)
  – Production planning under competitors behavior uncertainty.
    • Two stage stochastic programming (2SLPwR-MINLP)
    • Discount rate (First stage variable)
Problem statement – Cooperative scenario (demand uncertainty problem)

- **Integer Variables**
  - Distribution: $T(s,i,n,h,j)$
  - Production: $Q(i,n,h)$
  - Inventory: $W(s,i,n,h)$
  - Backorder: $E(s,i,n,h)$
  - Subcontracting: $V(s,i,n,h)$

- Minimize expected total cost (production, inventory distribution and backorder costs).

\[
\begin{align*}
    z_1(g) &= \sum_{iG} \sum_{iG} \sum_{n=1}^{N} \sum_{h=1}^{H} a_{in} Q_{inh}(1+e_b)^h + \sum_{s} \sum_{n=1}^{N} \sum_{h=1}^{H} \sum_{c_{inh}} W_{inh}(1+e_b)^h + \sum_{iG} \sum_{n=1}^{N} \sum_{h=1}^{H} b_{inh} E_{inh}(1+e_b)^h \\
    &+ \sum_{iG} \sum_{n=1}^{N} \sum_{h=1}^{H} \sum_{d_{inh}} V_{inh}(1+e_b)^h + \sum_{iG} \sum_{n=1}^{N} \sum_{h=1}^{H} \sum_{j=1}^{J} k_{inh} T_{inhj}(1+e_b)^h
\end{align*}
\]

Probability of occurrence $N_s$

\[N_1 + N_2 + \ldots + N_s = 1\]
Case study

- 2 Supply Chains
  - Plant 1 and 2 – SC1
  - Plant 3 and 4 – SC2
- 4 Distribution centers (intermediate consumers).
- 2 Products (Plant 1 – Plant 4).
- Time horizon of 3 months.
- Other data:

-20% Below nominal demand
+20% Above nominal demand

<table>
<thead>
<tr>
<th>Demand</th>
<th>Distr 1</th>
<th>Distr 2</th>
<th>Distr 3</th>
<th>Distr 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>t1</td>
<td>t2</td>
<td>t3</td>
<td>t1</td>
</tr>
<tr>
<td>P1</td>
<td>1000</td>
<td>3000</td>
<td>5000</td>
<td>820</td>
</tr>
<tr>
<td></td>
<td>2400</td>
<td>5300</td>
<td>820</td>
<td>1230</td>
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<tr>
<td>P2</td>
<td>650</td>
<td>910</td>
<td>3000</td>
<td>500</td>
</tr>
<tr>
<td></td>
<td>650</td>
<td>720</td>
<td>720</td>
<td>400</td>
</tr>
</tbody>
</table>

Liang (2005).
Liang (2008).

Enhancing decision making process in a cooperative and competitive environment
Production levels - cooperative

- Deterministic

![Deterministic - Production Levels](image)

- Two stage model

![Two stage Results](image)

Enhancing decision making process in a cooperative and competitive environment
Distribution levels - cooperative

• Deterministic

Scenario 1

Distribution level (products)

Dist1 Dist2 Dist3 Dist4

Plant4 Plant3 Plant2 Plant1

Scenario 2

Distribution level (products)

Dist1 Dist2 Dist3 Dist4

Plant4 Plant3 Plant2 Plant1

Scenario 3

Distribution level (products)

Dist1 Dist2 Dist3 Dist4

Plant4 Plant3 Plant2 Plant1

• Two stage model

Scenario 1

Distribution level (products)

Dist1 Dist2 Dist3 Dist4

Plant4 Plant3 Plant2 Plant1

Scenario 2

Distribution level (products)

Dist1 Dist2 Dist3 Dist4

Plant4 Plant3 Plant2 Plant1

Scenario 3

Distribution level (products)

Dist1 Dist2 Dist3 Dist4

Plant4 Plant3 Plant2 Plant1

Enhancing decision making process in a cooperative and competitive environment
Economic analysis - cooperative

**Deterministic**

<table>
<thead>
<tr>
<th>$</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>G1</td>
<td>G2</td>
<td>G1</td>
</tr>
<tr>
<td>Production Cost</td>
<td>355910</td>
<td>182610</td>
<td>485720</td>
</tr>
<tr>
<td>Storage Cost</td>
<td>7629</td>
<td>4520</td>
<td>10172</td>
</tr>
<tr>
<td>Backorder Cost</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Subcontracting Cost</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Distribution Cost</td>
<td>31613</td>
<td>10464</td>
<td>42528</td>
</tr>
<tr>
<td>Delivery time (h)</td>
<td>852</td>
<td>1135</td>
<td>1423</td>
</tr>
<tr>
<td>Total cost</td>
<td>592746</td>
<td>802506</td>
<td>1012469</td>
</tr>
</tbody>
</table>

**Two stage model**

<table>
<thead>
<tr>
<th>$</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>G1</td>
<td>G2</td>
<td>G1</td>
</tr>
<tr>
<td>Production Cost</td>
<td>442354</td>
<td>96166</td>
<td>442354</td>
</tr>
<tr>
<td>Storage Cost</td>
<td>10011</td>
<td>2297</td>
<td>10681</td>
</tr>
<tr>
<td>Backorder Cost</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Subcontracting Cost</td>
<td>0</td>
<td>0</td>
<td>86635</td>
</tr>
<tr>
<td>Distribution Cost</td>
<td>35041</td>
<td>7527</td>
<td>43587</td>
</tr>
<tr>
<td>Delivery time (h)</td>
<td>857</td>
<td>1133</td>
<td>1423</td>
</tr>
<tr>
<td>Expected total cost</td>
<td>841933</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Expected value of the perfect information (EVPI):
deterministic solutions ($802,573) -
expected total cost ($841,933)
EVPI:-39,360 $.

Enhancing decision making process in a cooperative and competitive environment
Problem statement – Competitive scenario

- Integer Variables
  - Distribution \( T(s,i,n,h,j) \)
  - Production \( Q(s,i,n,h) \)
  - Inventory \( W(s,i,n,h) \)
  - Backorder \( E(s,i,n,h) \)
  - Subcontracting \( V(s,i,n,h) \)
  - Price rate \( Prate \)

- Sets
  - \( i \) = Production Source
  - \( n \) = Product
  - \( h \) = Time
  - \( j \) = Markets
  - \( s \) = Scenarios

- Minimize the expenses of the buyers (nonlinear model).

\[
\min \text{CST}(g) = \sum_{s} N_s \left( \sum_{i \in I(g)} \sum_{n} \sum_{h} P_{s in} T_{s inh} Prate \right) + \sum_{s} \frac{1}{s} \left( \sum_{i \in I(g)} \sum_{n} \sum_{h} P_{s in} T_{s inh} Disc_s + zn(s) \right)
\]

- Minimize expected total cost (production, inventory distribution and backorder costs).

\[
zn_s = \sum_{i \in I(g)} \sum_{n=1}^{N} \sum_{h=1}^{H} a_{in} Q_{s inh} (1+e_{n,h})^h + \sum_{i \in I(g)} \sum_{n=1}^{N} \sum_{h=1}^{H} c_{in} W_{s inh} (1+e_{n,h})^h + \sum_{i \in I(g)} \sum_{n=1}^{N} \sum_{h=1}^{H} b_{in} E_{s inh} (1+e_{n,h})^h
\]

Enhancing decision making process in a cooperative and competitive environment
Results - competitive

- Deterministic solutions (Payoff matrix Chapter 7)
  - Discount rate
    | s | s1 | s2 | s3 | s4 |
    |---|----|----|----|----|
    | s=scenarios | 0.3 | 0.4 | 0.4 | 0.3 |
    | Best solution of SC1 | 0.3 | 0.4 | 0.4 | 0.3 |

- First stage variable (SC1 Discount rate 0.3%)
  
  SC2 reduces its prices meanwhile obtains more benefits

Enhancing decision making process in a cooperative and competitive environment
# Economic analysis

<table>
<thead>
<tr>
<th></th>
<th>Deterministic</th>
<th>Expected value</th>
<th>EVPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expenses of buyers</td>
<td>6,096,228</td>
<td>5,295,364</td>
<td>799,828</td>
</tr>
<tr>
<td>(CST, $)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total cost ($)</td>
<td>802,791</td>
<td>803,214</td>
<td>0.05% worse</td>
</tr>
<tr>
<td>Sales ($)</td>
<td>5,293,438</td>
<td>4,493,150</td>
<td>15.11% worse</td>
</tr>
</tbody>
</table>

Enhancing decision making process in a cooperative and competitive environment
Exogenous source of demand uncertainty

- Once solved the Competitive problem it can be formulated as the typical demand uncertainty problem

**Apparent demand:** hidden part of the demand (due to the competitors behavior)

**Conclusions**
- The competitors behavior represents a new **source of uncertainty**.
- Large **improvements** can be obtained by considering cooperation and competition among SC’s.
Outline

- Motivation
- Introduction
- State of the art
- Open issues and Goals
- Cooperative and competitive analysis
- Tactical decision level
  - Tactical-operational
  - Uncertainty Management
  - Robust DM tools
- Conclusions

Main Goal

- Study the effect of SC’s competition/cooperation scenarios under MOO analysis
- Develop a **bargaining tool**
Mathematical model

Objective functions

- Minimize total cost

\[ Min \ z_1(g) = \sum_{i \in I, G(i,g)} \sum_{n} \sum_{h} a_{ih} Q_{ih} (1 + e_b)^h + \sum_{i \in I, G(i,g)} \sum_{n} \sum_{h} c_{ih} W_{ih} (1 + e_b)^h \]

- Minimize total delivery time

\[ Min \ z_2(g) = \sum_{i \in I, G(i,g)} \sum_{n} \sum_{h} \sum_{j} \left[ \frac{U_{ij}}{S_{ijn}} \right] T_{ijn} \]

- Minimize the expenses of the buyers

\[ Min \ CST(g) = \sum_{i \in I, G(i,g)} \sum_{n} \sum_{h} \sum_{j} P_{ijn} T_{ijn} P_{rate} + z_1 \]
Proposed Framework

<table>
<thead>
<tr>
<th>SC2 (B)</th>
<th>0.0%</th>
<th>0.1%</th>
<th>0.2%</th>
</tr>
</thead>
<tbody>
<tr>
<td>SC1 (A)</td>
<td>(A,B)</td>
<td>(A,B)</td>
<td>(A,B)</td>
</tr>
</tbody>
</table>

Enhancing decision making process in a cooperative and competitive environment
Case study

- 2 Supply Chains
  - Plant 1 and 2 – SC1
  - Plant 3 and 4 – SC2
- 4 Distribution centers (intermediate consumers).
- 2 Products (Plant 1 – Plant 4).
- Time horizon of 3 months.
- Other data:

  - $a(i,n)$ Production cost of the product $n$ at source $i$.
  - $c(i,n)$ Inventory cost of the product $n$ at source $i$.
  - $d(i,n)$ Backorder cost of the product $n$ at source $i$.
  - $l(i,n)$ Man hours by unit of product $n$ produced at source $i$.
  - $r(i,n)$ Machine hours by unit of product $n$ produced at source $i$.

**Distribution cost and delivery time**

<table>
<thead>
<tr>
<th>Demand</th>
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<td>P1</td>
<td>1000</td>
<td>3000</td>
<td>5000</td>
<td>820</td>
</tr>
<tr>
<td></td>
<td>820</td>
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<td>4000</td>
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<tr>
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<tr>
<td></td>
<td>1230</td>
<td>3400</td>
<td>3000</td>
<td>5300</td>
</tr>
<tr>
<td>P2</td>
<td>650</td>
<td>910</td>
<td>3000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>910</td>
<td>3000</td>
<td>500</td>
<td></td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>720</td>
<td>2400</td>
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<td>720</td>
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<td>300</td>
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<td>1150</td>
<td>710</td>
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</tr>
<tr>
<td></td>
<td>1150</td>
<td>710</td>
<td>1050</td>
<td></td>
</tr>
<tr>
<td></td>
<td>710</td>
<td>1050</td>
<td>3100</td>
<td></td>
</tr>
</tbody>
</table>

Enhancing decision making process in a cooperative and competitive environment.

SC1 and SC2 cost analysis:

- Minimize Total Cost
- Minimize Total delivery Time

Worse Solution!!

Pareto Solutions

Cooperative

Total Cost

8 6 4 2 0

SC2 SC1
Competitive Results - Payoff Matrix

Conclusions

• An integrated multi-objective and Game Theory optimization framework has been developed including multiple SC’s into the problem formulation.
  – A new methodology to select the best option among different entities (i.e. producers and customers) has been developed.
Several concepts have been included into the typical SC scope in order to improve the SC competitiveness in cooperative and competitive environments.

- Typical SC problems have been reformulated in order to consider multiple Supply Chains under cooperation or competition.
- The role of 3rd parties has been included in the decision-making process.
- Multiple parameters have been identified and studied to analyze the behavior of the competitors (Product prices and product quality).
- Total Quality Control (TQC) in SCM models.
- Apparent demand has been identified as a new concept in SCM under competitive analysis.
- Game Theory has been exploited as an optimization tool to manage uncertainty.
Acknowledgments

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- The Spanish *Ministerio de Economía y Competitividad* and the *European Regional Development Fund*, both supporting the present research under the Projects EHMAN (DPI2009-09386) and SIGERA (DPI2012-37154-C02-01).

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Enhancing decision making process in a cooperative and competitive environment

CEPIMA:
Miguel Zamarripa
Prof. Antonio Espuña

CAPSE:
Prof. Carlos Mendez
Adrian Aguirre

Thank you for your kind attention

Center for Process and Environmental Engineering (CEPIMA)

November 19, 2013
Enhancing decision making process in a cooperative and competitive environment