Supply Chain Supernetworks with Suppliers Risk Diversification

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Reliable Supply Chain

- Starts from reliable suppliers
- Supplier selection multicriteria
  - Benefits vs. Risks
Suppliers Selection

- Single source
  - Improved bargaining power to reduce costs
  - Decreased effort to track supplier performance and manage relationships
  - Improved innovation and design collaboration
  - Improved plan synchronization and information exchange
  - Improved supplier responsiveness

Cost Reduction
## Suppliers Selection

<table>
<thead>
<tr>
<th>Risk Category</th>
<th>Examples</th>
</tr>
</thead>
</table>
| Capacity Risk         | • Output variability / availability  
                     | • Lead time variability                      |
| Catastrophic Risk     | • Natural disasters                          
                     | • War & terrorism                            |
| Quality Risk          | • Specification non-compliance                |
| Financial Risk        | • Foreign exchange rates                      
                     | • Vendor liquidity / viability                |
| Management Risk       | • Embezzlement                                
                     | • Fraud                                       |
| Contractual Risk      | • Intellectual property protection            |
| Market Risk           | • Increased competitiveness from global       
                     |     competitors                               |
Risks

Risks from suppliers

- Japan earthquake and tsunami
- Parts shortage
  - Automobile industry: Toyota, Ford, GM, Honda,…
  - Electronic companies: Smart Phones, iPad,…
  - the earthquake-damaged Japanese plants produce 25 percent of the world's silicon wafers
The Hackett Group’s Key Issues Study

Supply Chain Key Issues
(% of respondents citing the issue as ‘major’ or ‘critical’)

- Improving supply chain flexibility/agility: 92%
- Improving Cross-Organization Collaboration - Improve planning: 77%
- Mitigating supply chain risks (e.g., supply disruption, severe quality): 77%
- Mitigating rising/volatile raw materials or component costs: 77%
- Optimizing manufacturing and/or distribution network capacity and…: 69%
- Improving customer service/support: 64%
- Enabling the organization to offer new ‘Value-priced’ products and: 62%
- Minimizing and better managing supply chain complexity: 62%
- Improving speed to market of new products/product renovations: 58%
- Reducing overall cost-to-serve to customers: 57%
- Managing demand volatility: 54%
- Improving product quality: 54%
- Improving working capital performance: 46%
- Globalization or centralization of distribution and logistics: 38%
- Off Shoring manufacturing capacity for cost reduction: 31%
Suppliers Selection

- Multiple sources
  - Reduce risks and disruption
  - Maintain a steady competition
  - Improve flexibility

Choice, Flexibility and Competition
Risks from the manufacturers

- Toyota’s recall and “stop sale order” affected its part supplier CTS
- Toyota represents 3% of its annual sales
- General Motors, Ford and Chrysler represented 5% of total CTS sales
Assumptions

Without lost of generality, we consider one part/material suppliers in the network.

There are $M$ suppliers who compete with each other to supply the part/material to the manufacturers. A typical one is called $i$.

There are $N$ manufacturers producing a homogeneous product in a competitive way. A typical one is called $j$.

There are $L$ retailers who serve the $O$ markets in a competitive way. A typical retailer is called $l$; and a market is denoted as $k$.

Market demands are elastic that are functions of market prices.
Supply Chain Supernetwork

Suppliers

Manufacturers

Retailers

Markets

$q_{ij}$

$q_{ji}$

$q_{lk}$

$q_{lo}$
Suppliers Risk Diversification

In order to reduce risk, in practice, suppliers often access the risk factors of manufacturers and determine the allocation parameters of their parts.

Assume the allocation parameter of supplier $i$ to manufacturer $j$ is $\alpha_{ij}$, which could be the maximum percentage supplier $i$ will sell to manufacturer $j$. 
### Suppliers

<table>
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<tr>
<th>Production costs</th>
<th>Transaction costs with manufacturers</th>
<th>Revenues by selling parts to manufacturers</th>
</tr>
</thead>
</table>


Supplier $i, i=1,\ldots,N$

Maximize profit

$$M = \sum_{j=1}^{M} \rho_{ij}^{1}q_{ij} - f_{i}(Q^{1}) - \sum_{j=1}^{M} c_{ij}(q_{ij})$$

s.t.

$$q_{ij} \leq \alpha_{ij} \sum_{j=1}^{M} q_{ij}, \forall j$$

$$q_{ij} \geq 0, \forall j$$
Optimality Conditions

\[
\begin{aligned}
&-\rho_{ij}^1 + \frac{\partial f_i(Q^{1*})}{\partial q_{ij}} + \frac{\partial c_{ij}(q_{ij}^*)}{\partial q_{ij}} + \alpha_{ij} \xi_{ij}^{1*} - \xi_{ij}^{1*} \\
&\quad \times \left[ q_{ij} - q_{ij}^* \right] \\
&+ \alpha_{ij} \sum_{j=1}^{M} q_{ij}^* - q_{ij}^* \times \left[ \xi_{ij}^1 - \xi_{ij}^{1*} \right] \geq 0, \forall i, j
\end{aligned}
\]
Manufacturers, in turn, also access the risk factors of the suppliers and determine the order allocation parameters.

The order allocation parameters from manufacturer $j$ to supplier $i$ is denoted $\beta_{ij}$, which might represent the order percentage from supplier $i$. 
<table>
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<tr>
<th>Manufacturers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production costs</td>
</tr>
<tr>
<td>Transaction costs with suppliers</td>
</tr>
<tr>
<td>Transaction costs with retailers</td>
</tr>
<tr>
<td>Purchasing costs</td>
</tr>
<tr>
<td>Revenues by selling products to retailers</td>
</tr>
</tbody>
</table>
Manufacturer j, j=1,…,M

Maximize Profit

\[ \max \sum_{l=1}^{L} \rho_{jl}^2 q_{jl} - f_j(Q^2) - \sum_{i=1}^{N} \hat{c}_{ij}(q_{ij}) - \sum_{l=1}^{L} c_{jl}(q_{jl}) - \sum_{i=1}^{N} \rho_{ij}^1 q_{ij} \]

s.t.

\[ q_{ij} \leq \beta_{ij} \sum_{i=1}^{N} q_{ij}, \forall i \]

\[ \sum_{i=1}^{N} \gamma_j q_{ij} \geq \sum_{l=1}^{L} q_{jl} \]

\[ q_{ij} \geq 0, q_{jl} \geq 0, \forall i, l \]
Optimality Conditions

\[
\frac{\partial \hat{c}_{ij}(q^*_ij)}{\partial q_{ij}} + \rho_{ij}^1 - \xi_{ij}^{2*} + \xi_{ij}^{2*} \beta_{ij} + \xi_{j}^{3*} \gamma_j \times [q_{ij} - q^*_ij]
\]

\[
+ \left[ \frac{\partial c_{jl}(q^*_jl)}{\partial q_{jl}} + \frac{\partial f_j(Q^{2*})}{\partial q_{jl}} - \rho_{jl}^2 - \xi_{j}^{3*} \right] \times [q_{jl} - q^*_jl]
\]

\[
+ \sum_{i=1}^{N} \left[ \beta_{ij} \sum_{i=1}^{N} q_{ij}^* - q_{ij}^* \right] \times \left[ \xi_{ij}^{2} - \xi_{ij}^{2*} \right] + \left[ \sum_{i=1}^{N} \gamma_j q_{ij}^* - \sum_{l=1}^{L} q_{jl}^* \right] \times \left[ \xi_{j}^{3} - \xi_{j}^{3*} \right] \geq 0
\]
### Retailers and Markets

<table>
<thead>
<tr>
<th>Transaction costs with manufacturers</th>
<th>Handling costs</th>
<th>Purchasing costs</th>
<th>Revenue made from the markets</th>
<th>Selling prices are market driven</th>
<th>Demands are elastic</th>
</tr>
</thead>
</table>

- Selling prices are market driven
- Demands are elastic
Retailer l, \( l=1, \ldots, L \)

Retailer l serves the markets \( (k=1, \ldots, O) \)

\[
\rho_{lk}^{2*} + c_{lk}(Q^3) \begin{cases} 
= \rho_k^{3*}, & \text{if } q_{lk}^* \geq 0 \\
\geq \rho_k^{3*}, & \text{if } q_{lk}^* = 0 
\end{cases}
\]

\[
d_k(\rho_{3*}^3) \begin{cases} 
= \sum_{l=1}^{L} q_{lk}^*, & \text{if } \rho_k^{3*} \geq 0 \\
\leq \sum_{l=1}^{L} q_{lk}^*, & \text{if } \rho_k^{3*} = 0 
\end{cases}
\]
Market Equilibrium Conditions

\[
\begin{align*}
&\left[ \rho_{lk}^2 + c_{lk} (Q^{3*}) - \rho_k^{3*} \right] \times \left[ q_{jl} - q_{jl}^* \right] \\
&+ \sum_{k=1}^{O} \left[ \sum_{l=1}^{L} q_{lk}^* - d_k (\rho_k^{3*}) \right] \times \left[ \rho_k^3 - \rho_k^{3*} \right] \geq 0
\end{align*}
\]
Variational Inequality Formulation is developed to determine the quantities that each supplier sends to each manufacturer, the quantities that each manufacturer sells to each retailer, the quantities that each retailer sells to each market, the market demands, the market prices, the product selling prices, and the part selling prices.
Variational Inequality Formula

Determine \((Q^{1*}, Q^{2*}, Q^{3*}, \xi^{1*}, \xi^{2*}, \xi^{3*}, \rho^{3*})\) to solve the VIP:

\[
\sum_{i=1}^{N} \sum_{j=1}^{M} \left[ \frac{\partial f_i(Q^{1*})}{\partial q_{ij}} + \frac{\partial c_{ij}(q^{*}_{ij})}{\partial q_{ij}} + \frac{\hat{c}_{ij}(q^{*}_{ij})}{\partial q_{ij}} - \xi^{3*}_{j} \gamma_{j} - (1 - \alpha_{ij}) \xi^{1*}_{ij} \right]

-(1 - \beta_{ij}) \xi^{2*}_{ij} \times \left[ q_{ij} - q^{*}_{ij} \right] + \sum_{i=1}^{N} \sum_{j=1}^{M} \left[ \alpha_{ij} \sum_{j=1}^{M} q^{*}_{ij} - q^{*}_{ij} \right] \times \left[ \xi^{1}_{ij} - \xi^{1*}_{ij} \right]

+ \sum_{j=1}^{M} \sum_{l=1}^{L} \left[ \frac{\partial c_{jl}(q^{*}_{jl})}{\partial q_{jl}} + \frac{\partial f_j(Q^{2*})}{\partial q_{jl}} + c_{lk}(Q^{3*}) - \xi^{3*}_j \right] \times \left[ q_{jl} - q^{*}_{jl} \right]

+ \sum_{i=1}^{N} \sum_{j=1}^{M} \left[ \beta_{ij} \sum_{i=1}^{N} q^{*}_{ij} - q^{*}_{ij} \right] \times \left[ \xi^{2}_{ij} - \xi^{2*}_{ij} \right] + \sum_{j=1}^{M} \left[ \sum_{i=1}^{N} \gamma_{j} q^{*}_{ij} - \sum_{l=1}^{L} q^{*}_{jl} \right] \times \left[ \xi^{3}_{j} - \xi^{3*}_{j} \right]

+ \sum_{k=1}^{O} \left[ \sum_{l=1}^{L} q^{*}_{lk} - d_{k}(\rho^{3*}) \right] \times \left[ \rho^{3}_{k} - \rho^{3*}_{k} \right] \geq 0,

\forall (Q^{1}, Q^{2}, Q^{3}, \xi^{1}, \xi^{2}, \xi^{3}, \rho^{3}) \in \square^{NM+ML+LO+NM+NM+M+O}
Results

**Existence:** under certain conditions the solution to the VIP exists.

We solve the VIP problem using the Modified Projection Method.
Thank you