The Design of Effective and Robust Supply Chain Networks

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Outline

Design of Robust and Effective Supply Network Engineering Tools

- Network context
- Design methodology
- Modeling framework
- Solution methods
- Engineering tools
- Research tools
Supply Chain Network Design Problem

Raw material sources

Manufacturing Process

Finished Products

Distribution Channels

Markets

Deployed Supply Chain Network
Optimal Supply Network

DOMTAR CASE
Business Decisions

- Product-market selection
  - Prices
  - Lead-times
  - Fill-rates
  - Quality
  - Flexibility

- Value proposition
  - Internalization/externalization decisions
    - Product-markets
    - Resource deployment
    - Partner selection
    - International decisions
    - Financial decisions
    - Business environment
    - Performance indicators
Business Decisions

- Facilities location
- Capacity sizing decisions
- Technology selection decisions
- Facilities layout
- Real options
- Inventory positioning (OPP)
- Transportation means selection
- Facilities mission

- Resource deployment
- Partner selection
- Suppliers
  - Subcontractors
  - 3PLs

- Business

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Business Decisions

- Product-markets
  - Internalization/externalization decisions
  - Resource deployment
  - Partner selection
  - International decisions
  - Financial decisions
  - Business environment
  - Performance indicators

- Transfer prices
  - Port of entry/exit selection
  - Operational risk edging
Business Environment

- Aleatory events (A)
- Hazardous events (H)
- Totally uncertain events (T)

Deterministic Models

Stochastic Programming Models

Catastrophe Models

Min Max Regret

Information

Perfect
probable

Imperfect

Very low probability

Nil

Impact

None
Normal
Moderate
Serious
Catastrophic
Design Objective

Maximize Economic Value Added

Design Response Time

Total Cost

Total Revenue

Value added (Profit)

Discounted Cost (Value)

Design Objective

Maximize Economic Value Added
Design Methodology

DRESNET

- Network context
- Design methodology
  - Modeling framework
  - Solution methods
  - Engineering tools
  - Research tools
Timing of Decisions

Design Decisions
- Location
- Capacity
- Technology
- Markets
- Mission

User Decisions
- Demand management
- Supply
- Production
- Inventory
- Transportation
- ...

Possible environments \( (\omega) \)

Network design decision point
Network available for operations

Market analysis
Deployment
Design Methodology: Decision-making framework

Design Level
- Investment
- Deployment
- Policy making

User Level
Synchronization of supply and demand to minimize operations costs and maximize revenues

Anticipation of expected revenues and costs
Design methodology:
Decision-making framework

Design Level

**Design Model**
\[
\text{opt } E \left\{ C^d(x) + C^{du}(\hat{y}(x)) \mid I^d(t_0) \right\} \rightarrow I^d(t_0)
\]

**Anticipation**
\[
\hat{y}(x) \rightarrow x
\]

**Anticipated User-Model**
\[
\hat{y}(x) = \arg \text{opt } E \left\{ \hat{C}^u(\hat{y}) \mid \hat{I}^u(t_0) \right\} \rightarrow \hat{I}^u(t_0)
\]

User Level

**Decisions**
\[
\text{opt } E \left\{ C^u(y_\tau) \mid I^u(\tau) \right\} \rightarrow I^u(\tau), \tau \in T
\]

X * Design
Design methodology: Decision time hierarchy

Design level
Design decision
\[ x \in X \]
\[ I(t_0) \]

User level

Implementation Lead Time

Usage Period
\[ \hat{y} \in \hat{Y}^x \]
\[ y_\tau \in Y_\tau^{x*} \mid I^u(\tau) \]

Decision time hierarchy:

\[ t_0 \]

\[ t \]

\[ T^u \]

\[ T^u \]

\[ \tau \]

\[ \tau \]

\[ ... \]

\[ ... \]
Illustrative Case:
Multi-depot location problem

- Daily stochastic orders from customers
- Daily deliveries to ship-to points
- How many warehouses and where?

Design level
Potential DC locations
- Plant
  - $x^l$
  - $x^a$
User level
Ship-to points
- Time
- Compound Poisson demand process
Design methodology: scenarios building

A scenario $\omega \in \Omega$ is a compound event defined over all environments of planning horizon $t \in \hat{T}$

It is the juxtaposition of aleatory, hazardous and totally uncertain events.
Design Methodology: Concept definitions

- $\Omega =$ Set of all possible scenarios
- $p(\omega) =$ the probability of occurrence of scenario $\omega \in \Omega$
- $\Omega$ is divided in 3 mutually exclusives and collectively exhaustive subsets:
  - $\Omega^A$ includes only aleatory events
  - $\Omega^T$ includes aleatory and hazardous events
  - $\Omega^H$ includes, in addition, totally uncertain events

- $P(S) =$ probability of occurrence of a $S = A, H, T$ scenario
- $p^S(\omega) =$ probability of occurrence of $\omega \in \Omega^S$ within $S$ scenarios
Using *Stochastic Programming* (Ruszczynski and Shapiro, 2003) and *Robust Optimization* (Mulvey et al., 1995) concepts, the design problem can be formulated as follows:

\[
\text{opt } \bar{C}(x) + \sum_{S=A,H} p(S) \sum_{\omega \in \Omega^S} \psi^{S}(Q(x,\omega)) + p(T)\psi^{T}(Q(x))
\]

with:

\[
Q(x,\omega) = \text{opt } \hat{C}(\hat{y})
\]

\[
\psi^{S}(Q(x,\omega)) = p^{S}(\omega)[Q(x,\omega) + \kappa \rho(Q(x,\omega), \gamma)]
\]
Supply Chain Engineering Methodology

Identification of re-deployment and networking opportunities

Potential processes/rules models

Simulation / evaluation of logistic processes

New logistic process specifications

Deployment potential supply network

Supply network optimisation

New supply network specifications

Network Design

Identification of managerial / operational best practices

Extended Enterprise Supply Network

Implementation

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Strategic
Analysis

Conceptual Supply Network

Logical

Deployment level

Conceptual

Physical

Network Design
Modeling Framework

- Network context
- Design methodology
- Modeling framework
- Solution methods
- Engineering tools
- Research tools
Process/Product Structure and Technology

Raw materials \( p \in RM \)

Manufactured products \( p \in MP \)

Finished products \( p \in FP \)

Product (\( p \in P \))
- Dedicated technology
- Flexible technology
- Guzzino quantity

1. Supply Market
2. Inventory \( KS_1 \)
3. Bucking
4. Sawing
5. Drying
6. Planing/grading
7. Inventory \( KS_2 \)
8. Sales Market

1. 2. 3. 4. 5. 6. 7. 8. 9. 10. 11. 12. 13. 14.
Network Optimization Model Structure

Echelon structure  VS  General network
Part of the layout considered as fixed
Currently available technologies
Part of the facility which can be reconfigured
Installed capacity option which can be kept as is, disposed of or reconditioned
New capacity options which could be selected

\[ Y_{ls} = \text{Binary variable equal to 1 if layout } l \in L_s \text{ is used on site } s \]
\[ 0 \text{ otherwise.} \]

\[ Z_j = \text{Binary variable equal to 1 if capacity option } j \text{ is installed} \]
\[ 0 \text{ otherwise.} \]
Multi-period Model with Real Options

Illustration of the capacity option tree concept
Inventory Accounting for Seasonal Demands

\[
I_{pst}^S - 1 + U_{pst} = \sum_{d \in D_{ps}^o} X_{psdt}^I + I_{pst}^S
\]
Economies of Scale for Order Cycle and Safety Stocks

Risk pooling must be taken into account

\[ f_p \]

Inventory level

\[ f_p(X_{pw}, T_{pw}) = \rho_p\left(\frac{T_{pw}}{X_{pw}}\right)^{\theta_p} (X_{pw})^{\lambda_p} \]

Annual Flow

\[ X_{pw} \]

=> Depends on:
- Average lead time
- Warehouse throughput

=> Depends on transportation decisions
Modeling Market Response

Product-markets for a National Division

Markets

Spot markets

Contracts

VMI agreements

Logistics Policies

(Ulimited Recourse)

Signed (deterministic)

Potential (probabilistic)

Signed (deterministic)

Potential (probabilistic)

Network nodes

Demand zones

Customers

Potential customers

Customers

Potential customers

Competitor Offers

θᵢ obtained with discrete choice model
Modeling of Hazardous Incidents

Based on generic **multihazard** incidents

- \( \theta_l(\theta_w) \): duration, in periods number, of an incident at node \( l \) (arc \( w \))
- \( \alpha_l(\alpha_w) \): % of resources capacities available at node \( l \) (arc \( w \)) during an incident
- \( \beta_l \): % of inflation of demand zone \( l \) during an incident.

<table>
<thead>
<tr>
<th>Severity</th>
<th>Duration</th>
<th>SCN Resources Affected</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \alpha_l, l \in V )</td>
<td>( \theta_l, l \in V )</td>
<td>Sources</td>
</tr>
<tr>
<td>( \alpha_l, l \in F )</td>
<td>( \theta_l, l \in F )</td>
<td>Facilities</td>
</tr>
<tr>
<td>( \alpha_w, w \in W )</td>
<td>( \theta_w, w \in W )</td>
<td>Private infrastructure</td>
</tr>
<tr>
<td>( \beta_l, l \in D )</td>
<td>( \theta_l, l \in D )</td>
<td>Public infrastructure</td>
</tr>
</tbody>
</table>

**Magnitude of Impacts**
Probability distribution can be estimated using historical data on incidents at sites or in regions where the node is located.

\[ P(\theta_l = q), \quad q = 0, 1, \ldots, q_{\text{max}} \]
Robust Design Modeling

- Mission redundancy
  - Double coverage of each customer
- Insurance inventories
  - Size
  - Location
Fundamental Design Problem

Potential Facilities

\[ s \in S \]

\[ s \in S^d \]

\[ s \notin S^d \]

Production-storage site

Storage site

\[ \nu \in V \]

\[ d \in D \]
Revenues/Expenses Modeling

Country A

Supply Arc

P-DC s

Internal Arc

DC s’

Demand Arc

Country B

Price

Assignment of revenues and costs to arc and node variables when transportation is paid by the origin:

- **F_{pvst}**
  - Supply-order
  - Receiving
  - RM price
  - Transportation (currency v)

- **X_{pst}**
  - Production (c_{pks})
  - Handling (m_{pst})
  - Seasonal inventory (h_{pst})

- **U_{pst}**
  - Customer-order
  - Shipping
  - Transportation
  - Inventory in transit
  - Cycle/safety stock (h_{pdt})

- **F_{psst’}**
  - Supply-order
  - Receiving
  - Seasonal inventory (h_{psst’})
  - Transfer price (\pi_{psst’})
  - Transportation (f_{psst’})
  - Duties (\delta_{psst’})

- **I_{psst’}**
  - Customer-order
  - Shipping
  - Transportation
  - Inventory in transit
  - Cycle/safety stock (h_{psst’})

- **F_{ps’dt}**
  - Customer-order
  - Shipping
  - Transportation
  - Inventory in transit
  - Cycle/safety stock (h_{ps’dt})

P-DC s Income Statement

DC s’ Income Statement
Type of Model Used

Max \( E\{(1-Tax) \ [\text{Revenues} - (\text{Siting costs} + \text{Facilities capacity costs} + \text{Facilities operations costs} + \text{Procurement and Inventory costs} + \text{Transportation costs} + \text{Duties})]\}\) subject to

- Network configuration constraints
- Capacity option selection constraints
- Supply / Capacity / Demand constraints
- Material requirement constraints
- Inventory accounting constraints
- Flow conservation constraints
- Local content and transfer price constraints

\( \forall \) Scenarios

\( \Rightarrow \) Very large MIP with concave costs
Solution Methods

- Network context
- Design methodology
- Modeling framework
- Solution methods
- Engineering tools
- Research tools
Scenario Based Solution Approach

1. Use a sample $\Omega^N \subset \Omega$ of A, H and T scenarios
   - Monte-Carlo methods
   - Imaginative scenario creation methods

2. Solve a sample average design model

For risk neutral D-M and $X = \{x_j, j \in J\}$

$$x^* \mid Z(x^*) = \text{opt}\{Z(x_j), j \in J\}$$

$$Z(x_j) = \bar{C}^d(x_j) + \frac{(1-p(T))}{n_T} \sum_{\omega \in \Omega^{n_T}} Q(x_j, \omega) + \frac{p(T)}{n_T} \sum_{\omega \in \Omega^{n_T}} Q(x_j, \omega)$$

The complexity of the problem depends on the nature of $Q(x, \omega)$
Successive MIPs in trust region

• Based on gradient

\[ \nabla c_{ps}^k \]

\[ \phi X_{ps}^k \]

\[ X_{ps}^k \]

• Based on unit cost approximation
Initial Cuts

Example:
There must be enough capacity in the network to make all the required products

\[ \sum_{i \in I_p} \sum_{j \in J_i} \sum_{u \in U} b_{j} Z_{ju} \geq x_p \quad \forall p \in M \]

\[ x_p = \text{total product } p \text{ requirement} \]

\[ x = (1X)(I - G)^{-1} \]
Engineering Tools
Engineering tools

- Project workflow management
- Data management system
- Demand zone construction
- Transportation cost function estimator
- Inventory throughput function estimators
- Construction of multi-hazard functions
- Scenario generation system
- Model generator
- Solver
- Solution validation-evaluation tool
- Sensitivity analysis tools
- GIS based query-report system
- Status-quo validation-generation tool
Task: Capture the information required to generate the network lanes

2) Select a product category in the combo box
3) Select an origin-destination subset in the frame and specify how to generate the lanes data in the Mode Selection, Mode Assignment and Shipment Load combo boxes
4) Click the arrow on the left of the frame to display the subset of lanes selected and the default data screen

Stock SOAP

<table>
<thead>
<tr>
<th>Origin</th>
<th>Destination</th>
<th>Mode Selection</th>
<th>Transportation Mode</th>
<th>Shipment Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vendors (V)</td>
<td>Plants (NSP+SOP)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vendors (V)</td>
<td>Depots (DC,SW)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plants (NSP,SOP)</td>
<td>Plants (NSP,SOP)</td>
<td>Predetermined Mode</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plants (NSP,SOP)</td>
<td>Depots (DC,SW)</td>
<td>Predetermined Mode</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depots (DC,SW)</td>
<td>Plants (NSP,SOP)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depots (DC,SW)</td>
<td>Depots (DC,SW)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plants (NSP,SOP)</td>
<td>Customers (D)</td>
<td>Predetermined Mode</td>
<td></td>
<td>Customer Load</td>
</tr>
<tr>
<td>Depots (DC,SW)</td>
<td>Customers (D)</td>
<td>Predetermined Mode</td>
<td></td>
<td>Customer Load</td>
</tr>
</tbody>
</table>

Generate lanes

✓ Check this box when the task is completed
Aggregation of ship-to points in demand zones
Milage Calculators

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PC*MILER - [Route: NA, Practical, Open]

<table>
<thead>
<tr>
<th>Stop</th>
<th>Zip</th>
<th>City</th>
<th>Miles</th>
<th>Total</th>
<th>Cost</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>90086</td>
<td>Los Angeles, CA, Los Angeles</td>
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<tr>
<td></td>
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<td>New York, NY, New York</td>
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<td>2615.6</td>
<td>3097.16</td>
<td>43:14</td>
</tr>
</tbody>
</table>
Transportation Costs

Estimation from transportation industry data

LTL : CZARLite from SMC3 (www.smc3.com)

Origin: AL (36101)    Destination: VA (23218)    Distance : 692
Class: 100

<table>
<thead>
<tr>
<th>Rate/cwt</th>
<th>Weight</th>
<th>Charge</th>
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</thead>
<tbody>
<tr>
<td>68.56</td>
<td>1</td>
<td>0.69</td>
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<tr>
<td>68.56</td>
<td>458</td>
<td>314.00</td>
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<td>62.23</td>
<td>459</td>
<td>285.64</td>
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<td>486.64</td>
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<tr>
<td>48.7</td>
<td>783</td>
<td>381.32</td>
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<tr>
<td>48.7</td>
<td>1639</td>
<td>798.19</td>
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<tr>
<td>39.91</td>
<td>1640</td>
<td>654.52</td>
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<td>39.91</td>
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<td>31.41</td>
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<td>31.41</td>
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<td>23108</td>
<td>3,077.99</td>
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<tr>
<td>10.26</td>
<td>23109</td>
<td>2,370.98</td>
</tr>
</tbody>
</table>

Taux de transport

Poids (cwt)
Estimation of transportation costs from historical data
Regression curve by transportation mode

Rate = 0.3013(distance)^{0.8153}
Inventory Costs (Capital + Storage)

Inventory holding cost

\[ \text{Inventory holding cost} = \text{Inventory Level} \times \text{Product Value} \times \text{Holding Rate} \]

\[ R^2 = 0.85, \quad \text{Inventory} = 12.86866(\text{flows})^{0.5311} \]
Research Tools

Network context
Design methodology
Modeling framework
Solution methods
Engineering tools
Research tools
Thank you for your attention

Questions ?