Introduction to Supply Chain Design
We know what a supply chain is . . .

Two or more parties linked by a flow of resources – typically material, information, and money – that ultimately fulfill a customer request.
... and that they involve multiple parties ... 

... with complex and non-linear relationships ...
... and that they can take many different forms.
But, what is supply chain design?
What do we mean by “design”?

**design**  
*verb*  
\textit{di-zîn}  
- to plan and make decisions about (something that is being built or created)  
- to create the plans, drawings, etc., that show how (something) will be made  
- to plan and make (something) for a specific use or purpose

http://www.merriam-webster.com/dictionary

**design**  
*noun*  
a specification of an object (or \textit{system}), manifested by some agent, intended to \textit{accomplish} goals, in a particular \textit{environment}, using a set of primary (or \textit{fundamental}) \textit{components}, satisfying a set of \textit{requirements}, subject to some \textit{constraints}.

adapted from Ralph, P. and Wand, Y. (2009), “A proposal for a formal definition of the design concept”.
Why is Supply Chain Design important?
Because you have choices!

• There are many different ways to:
  ■ Forecast product demand
  ■ Position and manage inventory
  ■ Move product between facilities
  ■ Segment and collaborate with customers
  ■ Select and work with suppliers
  ■ Organize the supply chain function
  ■ Select locations for manufacturing and distribution
  ■ etc.

• There is no single best way for all situations – even within a single firm!
Quick Review: Demand Forecasting

### Product Technology

<table>
<thead>
<tr>
<th>Current (Have History)</th>
<th>New (No History)</th>
</tr>
</thead>
</table>
| **Market Penetration** | Forecasting Approach:  
Quantitative analysis of similar situations with item using history  
Time Series, Exponential Smoothing, Regression |
| **Product Development** | Forecasting Approach:  
Analysis of similar items: “looks-like” analysis or analogous forecasting  
Regression of “looks like” items |
| **Market Development** | Forecasting Approach:  
Customer and market analysis to understand market dynamics and drivers  
Customer Panels, Experimental |
| **Diversification** | Forecasting Approach:  
Scenario planning & analysis to understand key uncertainties & factors  
Delphi, Expert Panel, Scenario Planning, Bass Diffusion |

Quick Review: Demand Forecasting

- Forecasts are always wrong
  - Use ranges & track forecast error
- Aggregated forecasts are more accurate
  - Risk pooling reduces CV
- Shorter time horizon forecasts are more accurate
  - Postpone customization as late as possible

\[
e_t = A_t - F_t
\]

- Mean Deviation (MD)
  \[
  MD = \frac{\sum_{t=1}^{n} e_t}{n}
  \]
- Mean Absolute Percent Error (MAPE)
  \[
  MAPE = \frac{\sum_{t=1}^{n} \left| \frac{e_t}{A_t} \right|}{n}
  \]
- Root Mean Squared Error (RMSE)
  \[
  RMSE = \sqrt{\frac{\sum_{t=1}^{n} e_t^2}{n}}
  \]
Quick Review: Inventory Management

Policy: How much to order and when

- **EOQ** – deterministic demand with infinite horizon
  - Trading off fixed and variable costs
  - Order $Q^*$ every $T^*$ time periods / Order $Q^*$ when $IP=\mu_{DL}$
- **Newsvendor** – variable demand over single period
  - Trading off shortage and excess costs
  - Order $Q^*$ at start of period where $P[x\leq Q]=CR$

![Diagram showing EOQ and Newsvendor policies against demand variability and horizon]

- **EOQ**
- **Newsvendor**
- **Demand Variability**
- **Horizon**
Quick Review: Periodic vs. Continuous

**Continuous Review (s,Q)**
- Order Q if IP ≤ s

**Periodic Review (R, S)**
- Order S-IP every R periods

\[ s = \mu_{DL} + k\sigma_{DL} \]

\[ Q^* = \sqrt{\frac{2c_i D}{c_e}} \]

\[ S = \mu_{DL+R} + k\sigma_{DL+R} \]

Q \rightarrow D*R, s \rightarrow S, L \rightarrow L+R
Quick Review: Transportation Options

**One-to-One** – direct or point to point movements from origin to destination

**One-to-Many** – multi-stop moves from a single origin to many destinations

**Many-to-Many** – moving from multiple origins to multiple destinations usually with a hub or terminal
Quick Review: Total Cost Equation

\[ TC = cD + c_p \left( \frac{D}{Q} \right) + c_e \left( \frac{Q}{2} + k\sigma_{DL} + DL \right) + c_s P[StockOutType] \]

- Connection to Forecasting & Transportation
  - Forecasting Impact – expected demand and error
  - Transportation Impact – costs and lead time

- Setting Safety Stock
  - Service Based Metrics – set k to meet expected LOS
  - Cost Based Metrics – find k that minimizes total costs

\[ \mu_{DL} = \mu_L \mu_D \quad \sigma_{DL} = \sqrt{\mu_L \sigma_D^2 + \left(\mu_D\right)^2 \sigma_L^2} \]
How to select the right design?
How do you decide?

• Supply chain design is an art & science
  ■ A science because we can . . .
    ♦ Quantify the impact of different choices
    ♦ Find the optimal trade-offs between costs and service
    ♦ Select the best approach given characteristics of product, supplier, customers, markets, etc.
  ■ But, it is still an art because . . .
    ♦ Future is still uncertain – especially for longer term
    ♦ Assumptions rarely hold true completely
    ♦ Data are never completely accurate (regardless of selected precision!)
    ♦ Situations change over time – sometimes abruptly
# Segment by Product Characteristics

<table>
<thead>
<tr>
<th></th>
<th>Functional</th>
<th>Innovative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand</td>
<td>Predictable</td>
<td>Unpredictable</td>
</tr>
<tr>
<td>Life Cycle</td>
<td>Long &gt; 2 yrs</td>
<td>Short &lt; 1 yr</td>
</tr>
<tr>
<td>Margin</td>
<td>5% to 20%</td>
<td>20% to 60%</td>
</tr>
<tr>
<td>Variety</td>
<td>Low (10-20)</td>
<td>High</td>
</tr>
<tr>
<td>Error at Production</td>
<td>~10%</td>
<td>~40-100%</td>
</tr>
<tr>
<td>Avg Stockout Rates</td>
<td>1% to 2%</td>
<td>10% to 40%</td>
</tr>
<tr>
<td>Forced Mark down</td>
<td>0%</td>
<td>10% - 25%</td>
</tr>
<tr>
<td>Lead time for MTO</td>
<td>6 mon to 1 yr</td>
<td>1 day to 2 wks</td>
</tr>
<tr>
<td>Supply Chain Objective</td>
<td>Efficiency</td>
<td>Match Supply &amp; Demand</td>
</tr>
</tbody>
</table>

## Segment by Product Characteristics

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<tr>
<td><strong>Demand Forecasting</strong></td>
<td>• Time series analysis with detailed trends &amp; seasonality</td>
<td>• Qualitative Methods</td>
</tr>
<tr>
<td><strong>Approach</strong></td>
<td></td>
<td>• “Looks like” analysis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Bass Model</td>
</tr>
<tr>
<td><strong>Inventory</strong></td>
<td>• Periodic review policies</td>
<td>• Single period models</td>
</tr>
<tr>
<td><strong>management</strong></td>
<td>• Build up inventory for peaks</td>
<td>• Forward placement for initial launch</td>
</tr>
<tr>
<td><strong>Transportation</strong></td>
<td>• Ocean and Full Truckload (TL)</td>
<td>• Air, Parcel, and LTL</td>
</tr>
<tr>
<td><strong>Management</strong></td>
<td>• Minimum Order Quantities to DCs</td>
<td>• Ship direct to store</td>
</tr>
<tr>
<td></td>
<td>• Cost dominates speed</td>
<td>• Speed dominates cost</td>
</tr>
</tbody>
</table>

- These are directional segments – not hard and fast rules
- Most firms use a “portfolio” of supply chains to be successful.
- Functional products can be “innovative” – new products, promotions, etc.
- Over time, “innovative” products can become functional
Situations Change

• **High Tech Components**
  - **Computer chips**
    - Market has shifted from PCs to Laptops to Tablets to Smartphones
    - Cost of chips in Smartphones is ~ 1/5 that of in PCs!
  - **Memory Storage**
    - Price has dropped from 1.50 $/MB in 2000 to 0.56 ¢/MB in 2015

• **Pharmaceutical Industry**
  - New drugs are protected by patents – exclusivity
  - Drugs eventually move off of patent and generic manufacturers can then produce them
## Supply Chain Portfolio

**Original HP Inkjet SC: Early 1990’s**

<table>
<thead>
<tr>
<th></th>
<th>Fast / High Cost</th>
<th>Intermediate Design</th>
<th>Slow / Low Cost</th>
</tr>
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<tbody>
<tr>
<td><strong>Manufacturing Location</strong></td>
<td>On shore (e.g., US/Europe)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>International Shipping</strong></td>
<td>Rail/Truck</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Final Assembly Location</strong></td>
<td>On Shore</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Order Fulfillment Location</strong></td>
<td>On Shore (Factory/DC)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Inventory Stocking Model</strong></td>
<td>Build to Stock</td>
<td></td>
<td></td>
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# Supply Chain Portfolio

Postponement Inkjet SC: Late 1990’s

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<tbody>
<tr>
<td><strong>Manufacturing Location</strong></td>
<td></td>
<td></td>
<td>Off shore (e.g., China, Vietnam)</td>
</tr>
<tr>
<td><strong>International Shipping</strong></td>
<td></td>
<td></td>
<td>Ocean</td>
</tr>
<tr>
<td><strong>Final Assembly Location</strong></td>
<td>On Shore</td>
<td></td>
<td></td>
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<tr>
<td><strong>Order Fulfillment Location</strong></td>
<td>On Shore (Factory/DC)</td>
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<td></td>
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<tr>
<td><strong>Inventory Stocking Model</strong></td>
<td>Configure to Order</td>
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# Supply Chain Portfolio

## Cost Competition Inkjet: 2000’s

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<tbody>
<tr>
<td>Manufacturing Location</td>
<td>Green</td>
<td>Yellow</td>
<td>Red</td>
</tr>
<tr>
<td>International Shipping</td>
<td>Green</td>
<td>Yellow</td>
<td>Red</td>
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- **Off shore (e.g., China, Vietnam)**
- **Ocean**
- **Off Shore**

## Supply Chain Design Portfolio

Decision variables for SC Design:
(One option is chosen from each column)

<table>
<thead>
<tr>
<th>Decision Variable</th>
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<th>Slow / Low Cost</th>
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<tbody>
<tr>
<td>Manufacturing Location</td>
<td>On shore (e.g., US/Europe)</td>
<td>Near shore (e.g., Mexico/Romania)</td>
<td>Off shore (e.g., China, Vietnam)</td>
</tr>
<tr>
<td>International Shipping</td>
<td>Air Freight</td>
<td>Rail/Truck</td>
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Roadmap of SC2x – Supply Chain Design
Roadmap for CTL.SC2x

- Design of Physical Flows
- Design of Financial Flows
- Design of Information Flows
- Design of the Organization
Designing the Physical Flow

• How should materials flow through a supply chain?
  ■ Modeling the problem
    ♦ Transportation & Transshipment Problems
    ♦ Facility Location Problem
    ♦ Supply Chain Network Design Problem
  ■ Solving the problem
    ♦ Finding the balance between costs and level of service
    ♦ Optimization of Mixed Integer Linear Programs
  ■ Interpreting and implementing the solution
    ♦ Conducting sensitivity analysis of solutions
    ♦ Using optimization as a decision support tool
    ♦ Running network design projects in the real-world
Understanding the Financial Flow

How to translate Supply Chain concepts and actions . . .

- Inventory levels by type (raw, WIP, finished goods)
- Facility, equipment, labor, or software/system investments
- Outsourcing vs. Insourcing

. . . into the language of the Chief Financial Officer (CFO).

- Income Statements (Profit & Loss)
- Balance Sheets (Assets & Liabilities)
- Cash Flows (sources and uses of cash by activity)

Discuss Three Main Concepts & Tools

- Activity Based Costing
- Working Capital (Cash-to-Cash Cycle)
- Discounted Cash Flow Analysis
Managing the Information Flow

**Source:**
*Working with suppliers*
- Procurement methods, objective, & strategies
- Auctions - why & how
- Optimized procurement
- Risk sharing & supply contracts

**Make:**
*Coordinating manufacturing*
- Production planning
- Bill of Material (BOM)
- Fixed horizon planning problem
- Material/Distribution Resource Planning (MRP/DRP) systems

**Deliver:**
*Collaborating with Customers*
- Challenges & obstacles
- Bullwhip effect
- Customer collaboration programs (CPFR, VMI, etc.)
- Sales & Operations Planning (S&OP)

Source: Supply-Chain Operations Reference (SCOR) Model from Supply Chain Council
Designing the Organization

• How should a supply chain be organized?
  ■ Business & Supply Chain Processes
    ✤ How should we map processes?
    ✤ How can we improve or re-engineer these processes?
  ■ Performance Metric Systems
    ✤ How to measure supply chain performance?
    ✤ How to establish metrics and metric systems?
  ■ Organizational Structure
    ✤ How should the supply chain function be organized?
    ✤ When and what to centralize/decentralize?
Questions, Comments, Suggestions?
Use the Discussion!

“Wilson’s excited to get started
– I hope you are too!”
Yankee Golden Retriever Rescued Dog
(www.ygrr.org)
Images & References

- Slide 5
  - Arntzen, B. MIT Center for Transportation & Logistics, Hi-Viz Research Project (2013)

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