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?

Image Source: Amtzen, B. MIT Center for Transportation & Logistics, Hi-Viz Research Project (2013)
What do we mean by “design”?

design  verb  de·sign  \di-ˈzīn\  
- 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 system), manifested by some agent, intended to accomplish goals, in a particular environment, using a set of primary (or fundamental) components, satisfying a set of requirements, subject to some constraints.

adapted from Ralph, P. and Wand, Y. (2009), “A proposal for a formal definition of the design concept”.

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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

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

Adapted from Kahn, Kenneth (2006) *New Product Forecasting.*
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)
\[ MAPE = \frac{\sum_{t=1}^{n} |e_t|}{A_t} \]

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 $P[x\leq Q]=CR$
Quick Review: Periodic vs. Continuous

**Continuous Review (s,Q)**
- Order Q if IP $\leq s$

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

$$S = \mu_{DL+R} + k\sigma_{DL+R}$$
$$Q^* = \sqrt{\frac{2c_iD}{c_e}}$$

$$S = \mu_{DL} + k\sigma_{DL} + R$$
$$Q \rightarrow D^*R, \quad s \rightarrow S, \quad L \rightarrow L+R$$
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

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

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

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

#### Postponement Inkjet SC: Late 1990’s

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<td><strong>Manufacturing Location</strong></td>
<td>On Shore</td>
<td></td>
<td>Off shore (e.g., China, Vietnam)</td>
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<tr>
<td><strong>International Shipping</strong></td>
<td>On Shore</td>
<td></td>
<td>Ocean</td>
</tr>
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### Supply Chain Portfolio

**Cost Competition Inkjet: 2000’s**

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

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Roadmap of SC2x – Supply Chain Design
Roadmap for CTL.SC2x

1. Design of Physical Flows
2. Design of Financial Flows
3. Design of Information Flows
4. 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?
Roadmap for CTL.SC2x

- Design of Physical Flows: 5 Lessons
- Design of Financial Flows: 4 Lessons
- Design of Information Flows: 8 Lessons
- Design of the Organization: 2 Lessons
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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- **Slide 31**
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