Objectives of Chapters 4, 5, 6

◆ Designing the SC Network: (Ch4, 5, 6)
  – Ch4 ➔ Explores how to design a distribution network
  – Ch5 ➔ Considers facility related decisions to be made when designing a SC network.
  – Ch6 ➔ Methodologies for evaluation of network design decisions under uncertainty are discussed.
Supply Chain Management (3rd Edition)

Chapter 6
Network Design in an Uncertain Environment
The Impact of Uncertainty on Network Design Decisions
Discounted Cash Flow Analysis
Representations of Uncertainty
Evaluating Network Design Decisions Using Decision Trees
AM Tires: Evaluation of Supply Chain Design Decisions Under Uncertainty
Making Supply Chain Decisions Under Uncertainty in Practice
Summary of Learning Objectives
The Impact of Uncertainty on Network Design

- Supply chain design decisions include investments in number and size of plants, number of trucks, number of warehouses.
- These decisions cannot be easily changed in the short-term.
- There will be a good deal of uncertainty in demand, prices, exchange rates, and the competitive market over the lifetime of a supply chain network.
- Therefore, building flexibility into supply chain operations allows the supply chain to deal with uncertainty in a manner that will maximize profits.
Discounted Cash Flow Analysis

- Supply chain decisions are in place for a long time, so they should be evaluated as a sequence of cash flows over that period.
- Discounted cash flow (DCF) analysis evaluates the present value of any stream of future cash flows and allows managers to compare different cash flow streams in terms of their financial value.
- Based on the time value of money – a dollar today is worth more than a dollar tomorrow.
Discounted Cash Flow Analysis

Discount factor = \( \frac{1}{1 + k} \)

\[ NPV = C_0 + \sum_{t=1}^{T} \left( \frac{1}{1 + k} \right)^t C_t \]

where

- \( C_0, C_1, ..., C_T \) is a stream of cash flows over \( T \) periods
- \( NPV \) = the net present value of this stream of cash flows
- \( k \) = rate of return

- Compare NPV of different supply chain design options
- The option with the highest NPV will provide the greatest financial return
NPV Example: Trips Logistics

◆ How much space to lease in the next three years
◆ Demand = 100,000 units
◆ Requires 1,000 sq. ft. of space for every 1,000 units of demand
◆ Revenue = $1.22 per unit of demand
◆ Decision is whether to sign a three-year lease or obtain warehousing space on the spot market
◆ Three-year lease: cost = $1 per sq. ft.
◆ Spot market: cost = $1.20 per sq. ft.
◆ \( k = 0.1 \)
NPV Example: Trips Logistics

For leasing warehouse space on the spot market:

Expected annual profit = 100,000 x $1.22 – 100,000 x $1.20 = $2,000

Cash flow = $2,000 in each of the next three years

\[
NPV\text{(no lease)} = C_0 + \frac{C_1}{1+k} + \frac{C_2}{(1+k)^2}
\]

\[
= 2000 + \frac{2000}{1.1} + \frac{2000}{1.1^2} = $5,471
\]
NPV Example: Trips Logistics

For leasing warehouse space with a three-year lease:

Expected annual profit = 100,000 x $1.22 – 100,000 x $1.00 = $22,000

Cash flow = $22,000 in each of the next three years

\[
NPV (\text{no lease}) = C_0 + \frac{C_1}{1+k} + \frac{C_2}{(1+k)^2}
\]

\[
= 22000 + \frac{22000}{1.1} + \frac{22000}{1.1^2} = $60,182
\]

The NPV of signing the lease is $54,711 higher; therefore, the manager decides to sign the lease

However, uncertainty in demand and costs may cause the manager to rethink his decision
Representations of Uncertainty

- Binomial Representation of Uncertainty
- Other Representations of Uncertainty
Binomial Representations of Uncertainty

- When moving from one period to the next, the value of the underlying factor (e.g., demand or price) has only two possible outcomes – up or down.
- The underlying factor moves up by a factor of \( u > 1 \) with probability \( p \), or down by a factor of \( d < 1 \) with probability \( 1-p \).
- Assuming a price \( P \) in period 0, for the multiplicative binomial, the possible outcomes for the next four periods:
  - Period 1: \( Pu, Pd \)
  - Period 2: \( Pu^2, Pud, Pd^2 \)
  - Period 3: \( Pu^3, Pu^2d, Pud^2, Pd^3 \)
  - Period 4: \( Pu^4, Pu^3d, Pu^2d^2, Pud^3, Pd^4 \)
Binomial Representations of Uncertainty

In general, for multiplicative binomial, period T has all possible outcomes $P^t d^{(T-t)}$, for $t = 0, 1, \ldots, T$.

From state $P^a d^{(T-a)}$ in period $t$, the price may move in period $t+1$ to either

- $P^{a+1} d^{(T-a)}$ with probability $p$, or
- $P^a d^{(T-a)+1}$ with probability $(1-p)$

Represented as the binomial tree shown in Figure 6.1 (p. 140)
Binomial Representations of Uncertainty

◆ For the additive binomial, the states in the following periods are:
  – Period 1: P+u, P-d
  – Period 2: P+2u, P+u-d, P-2d
  – Period 3: P+3u, P+2u-d, P+u-2d, P-3d
  – Period 4: P+4u, P+3u-d, P+2u-2d, P+u-3d, P-4d

◆ In general, for the additive binomial, period T has all possible outcomes P+tu-(T-t)d, for t=0, 1, …, T
Evaluating Network Design Decisions Using Decision Trees

- A manager must make many different decisions when designing a supply chain network.
- Many of them involve a choice between a long-term (or less flexible) option and a short-term (or more flexible) option.
- If uncertainty is ignored, the long-term option will almost always be selected because it is typically cheaper.
- Such a decision can eventually hurt the firm, however, because actual future prices or demand may be different from what was forecasted at the time of the decision.
- A *decision tree* is a graphic device that can be used to evaluate decisions under uncertainty.
Decision Tree Methodology

1. Identify the duration of each period (month, quarter, etc.) and the number of periods $T$ over which the decision is to be evaluated.

2. Identify factors such as demand, price, and exchange rate, whose fluctuation will be considered over the next $T$ periods.

3. Identify representations of uncertainty for each factor; that is, determine what distribution to use to model the uncertainty.

4. Identify the periodic discount rate $k$ for each period.

5. Represent the decision tree with defined states in each period, as well as the transition probabilities between states in successive periods.

6. Starting at period $T$, work back to period 0, identifying the optimal decision and the expected cash flows at each step. Expected cash flows at each state in a given period should be discounted back when included in the previous period.
Decision Tree Methodology: Trips Logistics

◆ Decide whether to lease warehouse space for the coming three years and the quantity to lease
◆ Long-term lease is currently cheaper than the spot market rate
◆ The manager anticipates uncertainty in demand and spot prices over the next three years
◆ Long-term lease is cheaper but could go unused if demand is lower than forecast; future spot market rates could also decrease
◆ Spot market rates are currently high, and the spot market would cost a lot if future demand is higher than expected
Trips Logistics: Three Options

- Get all warehousing space from the spot market as needed
- Sign a three-year lease for a fixed amount of warehouse space and get additional requirements from the spot market
- Sign a flexible lease with a minimum change that allows variable usage of warehouse space up to a limit with additional requirement from the spot market
Trips Logistics

- 1000 sq. ft. of warehouse space needed for 1000 units of demand
- Current demand = 100,000 units per year
- Binomial uncertainty: Demand can go up by 20% with \( p = 0.5 \) or down by 20% with \( 1-p = 0.5 \)
- Lease price = $1.00 per sq. ft. per year
- Spot market price = $1.20 per sq. ft. per year
- Spot prices can go up by 10% with \( p = 0.5 \) or down by 10% with \( 1-p = 0.5 \)
- Revenue = $1.22 per unit of demand
- \( k = 0.1 \)
Trips Logistics Decision Tree
(Fig. 6.2)
Trips Logistics Example

- Analyze the option of not signing a lease and obtaining all warehouse space from the spot market.
- Start with Period 2 and calculate the profit at each node.
- For $D=144$, $p=\$1.45$, in Period 2:
  
  \[
  C(D=144, p=1.45,2) = 144,000 \times 1.45 = 208,800
  \]
  
  \[
  P(D=144, p =1.45,2) = 144,000 \times 1.22 - C(D=144,p=1.45,2) = 175,680 - 208,800 = -33,120
  \]

- Profit at other nodes is shown in Table 6.1.
Trips Logistics Example

- Expected profit at each node in Period 1 is the profit during Period 1 plus the present value of the expected profit in Period 2.
- Expected profit $EP(D=, p=,1)$ at a node is the expected profit over all four nodes in Period 2 that may result from this node.
- $PVEP(D=,p=,1)$ is the present value of this expected profit and $P(D=,p=,1)$, and the total expected profit, is the sum of the profit in Period 1 and the present value of the expected profit in Period 2.
From node $D=120$, $p=1.32$ in Period 1, there are four possible states in Period 2.

Evaluate the expected profit in Period 2 over all four states possible from node $D=120$, $p=1.32$ in Period 1 to be:

$$EP(D=120, p=1.32, 1) = 0.25 \times P(D=144, p=1.45, 2) + 0.25 \times P(D=144, p=1.19, 2) + 0.25 \times P(D=96, p=1.45, 2) + 0.25 \times P(D=96, p=1.19, 2)$$

$$= 0.25 \times (-33,120) + 0.25 \times 4,320 + 0.25 \times (-22,080) + 0.25 \times 2,880$$

$$= -$12,000$$
The present value of this expected value in Period 1 is
\[ \text{PVEP}(D=12, p=1.32, 1) = \frac{\text{EP}(D=120, p=1.32, 1)}{(1+k)} \]
\[ = \frac{-12,000}{1+0.1} \]
\[ = -10,909 \]

The total expected profit \( P(D=120, p=1.32, 1) \) at node \( D=120, p=1.32 \) in Period 1 is the sum of the profit in Period 1 at this node, plus the present value of future expected profits possible from this node
\[ P(D=120, p=1.32, 1) = [(120,000 \times 1.22) - (120,000 \times 1.32)] + \text{PVEP}(D=120, p=1.32, 1) \]
\[ = -12,000 + (-10,909) = -22,909 \]

The total expected profit for the other nodes in Period 1 is shown in Table 6.2
For Period 0, the total profit $P(D=100, p=120, 0)$ is the sum of the profit in Period 0 and the present value of the expected profit over the four nodes in Period 1

$$EP(D=100, p=1.20, 0) = 0.25 \times P(D=120, p=1.32, 1) +$$
$$= 0.25 \times P(D=120, p=1.08, 1) +$$
$$= 0.25 \times P(D=96, p=1.32, 1) +$$
$$= 0.25 \times P(D=96, p=1.08, 1)$$

$$= 0.25 \times (-22,909) + 0.25 \times 32,073 + 0.25 \times (-15,273) + 0.25 \times 21,382$$

$$= $3,818$$

$$PVEP(D=100, p=1.20, 0) = EP(D=100, p=1.20, 0) / (1+k)$$

$$= $3,818 / (1 + 0.1) = $3,471$$
Trips Logistics Example

\[ P(D=100, p=1.20, 0) = 100,000 \times 1.22 - 100,000 \times 1.20 + PVEP(D=100, p=1.20, 0) \]
\[ = $2,000 + $3,471 = $5,471 \]

Therefore, the expected NPV of not signing the lease and obtaining all warehouse space from the spot market is given by \( NPV(Spot \, Market) = $5,471 \)
Trips Logistics Example

◆ Using the same approach for the lease option, NPV(Lease) = $38,364
◆ Recall that when uncertainty was ignored, the NPV for the lease option was $60,182
◆ However, the manager would probably still prefer to sign the three-year lease for 100,000 sq. ft. because this option has the higher expected profit
Evaluating Flexibility Using Decision Trees

- Decision tree methodology can be used to evaluate flexibility within the supply chain.
- Suppose the manager at Trips Logistics has been offered a contract where, for an upfront payment of $10,000, the company will have the flexibility of using between 60,000 sq. ft. and 100,000 sq. ft. of warehouse space at $1 per sq. ft. per year. Trips must pay $60,000 for the first 60,000 sq. ft. and can then use up to 40,000 sq. ft. on demand at $1 per sq. ft. as needed.
- Using the same approach as before, the expected profit of this option is $56,725.
- The value of flexibility is the difference between the expected present value of the flexible option and the expected present value of the inflexible options.
- The three options are listed in Table 6.7, where the flexible option has an expected present value $8,361 greater than the inflexible lease option (including the upfront $10,000 payment).
AM Tires: Evaluation of Supply Chain Design Decisions Under Uncertainty

◆ Dedicated Capacity of 100,000 in the United States and 50,000 in Mexico
  – Period 2 Evaluation
  – Period 1 Evaluation
  – Period 0 Evaluation

◆ Flexible Capacity of 100,000 in the United States and 50,000 in Mexico
  – Period 2 Evaluation
  – Period 1 Evaluation
  – Period 0 Evaluation
## Evaluating Facility Investments: AM Tires

### Table: Facility Costs and Demands

<table>
<thead>
<tr>
<th>Plant</th>
<th>Dedicated Plant</th>
<th>Flexible Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fixed Cost</td>
<td>Variable Cost</td>
</tr>
<tr>
<td>US 100,000</td>
<td>$1 million/yr.</td>
<td>$15 / tire</td>
</tr>
<tr>
<td>Mexico 50,000</td>
<td>4 million pesos/yr.</td>
<td>110 pesos/tire</td>
</tr>
</tbody>
</table>

U.S. Expected Demand = 100,000;  
Mexico Expected Demand = 50,000  
1 US$ = 9 pesos

Demand goes up or down by 20 percent with probability 0.5 and exchange rate goes up or down by 25 per cent with probability 0.5.
AM Tires

Period 0

RU=100
RM=50
E=9

Period 1

RU=120
RM=60
E=11.25

RU=120
RM=40
E=6.75

RU=120
RM=60
E=11.25

RU=120
RM=40
E=6.75

RU=80
RM=60
E=11.25

RU=80
RM=60
E=11.25

RU=80
RM=40
E=6.75

RU=80
RM=40
E=6.75

RU=80
RM=40
E=6.75

Period 2

RU=144
RM=72
E=14.06

RU=144
RM=72
E=8.44

RU=144
RM=72
E=8.44

RU=144
RM=48
E=14.06

RU=144
RM=48
E=8.44

RU=144
RM=48
E=8.44

RU=96
RM=72
E=14.06

RU=96
RM=72
E=8.44

RU=96
RM=72
E=8.44

RU=96
RM=48
E=14.06

RU=96
RM=48
E=8.44

RU=96
RM=48
E=8.44
AM Tires

Four possible capacity scenarios:
- Both dedicated
- Both flexible
- U.S. flexible, Mexico dedicated
- U.S. dedicated, Mexico flexible

For each node, solve the demand allocation model:

![Diagram showing plants and markets with possible connections between U.S. and Mexico.]
AM Tires: Demand Allocation for RU = 144; RM = 72, E = 14.06

<table>
<thead>
<tr>
<th>Source</th>
<th>Destination</th>
<th>Variable cost</th>
<th>Shipping cost</th>
<th>E</th>
<th>Sale price</th>
<th>Margin ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>U.S.</td>
<td>U.S.</td>
<td>$15</td>
<td>0</td>
<td>14.06</td>
<td>$30</td>
<td>$15</td>
</tr>
<tr>
<td>U.S.</td>
<td>Mexico</td>
<td>$15</td>
<td>$1</td>
<td>14.06</td>
<td>240 pesos</td>
<td>$1.1</td>
</tr>
<tr>
<td>Mexico</td>
<td>U.S.</td>
<td>110 pesos</td>
<td>$1</td>
<td>14.06</td>
<td>$30</td>
<td>$21.2</td>
</tr>
<tr>
<td>Mexico</td>
<td>Mexico</td>
<td>110 pesos</td>
<td>0</td>
<td>14.06</td>
<td>240 pesos</td>
<td>$9.2</td>
</tr>
</tbody>
</table>

Plants

- U.S.: 100,000
- Mexico: 50,000

Markets

- U.S.: 100,000
- Mexico: 6,000

Profit (flexible) = $1,075,055
Profit (dedicated) = $649,360
## Facility Decision at AM Tires

<table>
<thead>
<tr>
<th>Plant Configuration</th>
<th>NPV</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>Mexico</td>
</tr>
<tr>
<td>Dedicated</td>
<td>Dedicated</td>
</tr>
<tr>
<td>Flexible</td>
<td>Dedicated</td>
</tr>
<tr>
<td>Dedicated</td>
<td>Flexible</td>
</tr>
<tr>
<td>Flexible</td>
<td>Flexible</td>
</tr>
</tbody>
</table>
Making Supply Chain Design Decisions Under Uncertainty in Practice

- Combine strategic planning and financial planning during network design
- Use multiple metrics to evaluate supply chain networks
- Use financial analysis as an input to decision making, not as the decision-making process
- Use estimates along with sensitivity analysis
Summary of Learning Objectives

◆ What are the uncertainties that influence supply chain performance and network design?
◆ What are the methodologies that are used to evaluate supply chain decisions under uncertainty?
◆ How can supply chain network design decisions in an uncertain environment be analyzed?