Global Supply Chain Management

Outline

- Globalization Examples
- Globalization Trend
- Facility Location and Capacity Allocation
- Impact of Uncertainty on Network Design
- Discounted Cash Flow Analysis
- Representations of Uncertainty
- Network Design Decisions Using Decision Trees

Globalization Examples

- Apple iPods
  - Design and Marketing done in US
  - Engineering work done in India
  - Components manufactured in China
- Collaboration of best minds in the world to produce an innovative global product

Globalization Examples

- According to Asian Development Bank, the production of a very popular smart phoned involved 5 countries producing 14 parts and performing final assembly
  - 6 by Germany (e.g. camera, GPS)
  - 1 by Korea (application processor)
  - 3 by US (e.g. memory chips, blue tooth)
  - 4 by Japan (e.g. display, touch screen, flash memory)
  - Final assembly in China

Globalization Examples

- In production of a so called "American Car", most had most of its value was added overseas:
  - 30% in Korea for assembly
  - 17.5% in Japan for advanced technology components
  - 2.5%
  - 7.5% in Germany for design
  - 4% in Taiwan and Singapore for minor parts
  - 2.5% in the U.K. for advertising and marketing
  - 1.5% in Ireland and Barbados for data processing
- Thus, only 37% of the car's value was generated in America!

Globalization Examples

- The all-American Barbie doll's:
  - Hair comes from Japan
  - Its plastic body from Taiwan
  - Her cotton clothing comes from China
  - Only the molds and pigments are made in the US!

Globalization Trend

- Growth in Global Trade
  - In 1948, 23 countries in GATT (Global Agreement on Trade and Tariff)
  - WTO (World Trade Organization) was formed in 1995
  - China entered WTO in 2001
  - In 2012, 153 countries in WTO
- Tremendous growth in global trade in manufactured goods

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Globalization Trend

- According to Asian Development Bank, China's share of manufactured goods in:
- World Market
  - 50% of cameras
  - 25% of air conditioners & TVs
  - 25% of all washing machines
- US Market
  - 81% of toys
  - 72% of footwear
  - 54% of consumer electronics
  - 9% of apparel

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Models for Facility Location and Capacity Allocation

- A manager's goal when locating facilities and allocating capacities is to maximize overall profitability while providing customers with the appropriate responsiveness
- The following may be used in making a decision:
  - Location of supply sources and markets
  - Location of facility sites
  - Demand forecast by market
  - Facility, labor, and material costs by site
  - Transportation costs between each pair of sites
  - Inventory costs by site and as a function of quantity
  - Sale price product in different regions
  - Taxes and tariffs
  - Desired response time and other service factors.

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The Capacitated Plant Location Model

- The capacitated plant location model requires the following inputs:

n = number of potential plant locations/capacity

m = number of markets or demand points

D_j= annual demand from market j

K_i= potential capacity of plant i

f_i= annualized fixed cost of keeping plant i open

c_{ij}= cost of producing and shipping one unit from plant i to market j

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The Capacitated Plant Location Model

- The supply chain's goal is to determine a network design that maximizes profits. The model thus tries to minimize the cost of meeting the global demand. Define the following variables:

y_i= 1 if plant i is open, 0 otherwise

x_{ij}= quantity shipped from plant i to market j

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The Capacitated Plant Location Model

- The problem can then be formulated as the following integer program:

$$\text{Min} \quad \sum_{i=1}^{n} f_i y_i + \sum_{i=1}^{n}\sum_{j=1}^{m} c_{ij} x_{ij}$$

Subject to

$$\sum_{i=1}^{n} x_{ij} = D_j \qquad \text{for } j = 1,\ldots\ldots, m$$

$$\sum_{j=1}^{m} x_{ij} \le K_i y_i \qquad \text{for } i = 1,\ldots\ldots, n$$

$$y_i \in \{0,1\} \qquad \text{for } i = 1,\ldots\ldots, n$$

$$x_{ij} \ge 0$$

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The Capacitated Plant Location Model Example

- **Example 1**
  The VP of supply chain of a company has collected and summarized the data in the following table. The VP would like to know what would the lowest cost network look like for the case of high capacity so as to minimize the total cost of setting up and operating the network. Formulate this as a mathematical programming problem.

Supply Region	Demand Region Production and transportation costs (in thousands of dollars)/million units					Fixed costs (in thousands of dollars)	Capacity (in million units)
	North America	South America	Europe	Asia	Africa		
North America	81	92	101	130	115	9000	20
South America	117	77	108	98	100	6750	20
Europe	102	105	95	119	111	9750	20
Asia	115	125	90	59	74	6150	20
Africa	142	100	103	105	71	6000	20
Demand (in million units)	**12**	**8**	**14**	**16**	**7**		

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The Capacitated Plant Location Model Formulation

- The problem can then be formulated as follows:

$$\text{Min } 9000y_1 + 6750y_2 + 9750y_3 + 6150y_4 + 6000y_5 + 81x_{11} + 92x_{12} + 101x_{13} + 130x_{14} + 115x_{15}$$
$$+117x_{21} + 77x_{22} + 108x_{23} + 98x_{24} + 100x_{25} + 102x_{31} + 105x_{32} + 95x_{33} + 119x_{34} + 111x_{35}$$
$$+115x_{41} + 125x_{42} + 90x_{43} + 59x_{44} + 74x_{45} + 142x_{51} + 100x_{52} + 103x_{53} + 105x_{54} + 71x_{55}$$

Subject to

$$x_{11} + x_{21} + x_{31} + x_{41} + x_{51} = 12$$
$$x_{12} + x_{22} + x_{32} + x_{42} + x_{52} = 8$$
$$x_{13} + x_{23} + x_{33} + x_{43} + x_{53} = 14$$
$$x_{14} + x_{24} + x_{34} + x_{44} + x_{54} = 16$$
$$x_{15} + x_{25} + x_{35} + x_{45} + x_{55} = 7$$
$$x_{11} + x_{12} + x_{13} + x_{14} + x_{15} \le 20y_1$$
$$x_{21} + x_{22} + x_{23} + x_{24} + x_{25} \le 20y_2$$
$$x_{31} + x_{32} + x_{33} + x_{34} + x_{35} \le 20y_3$$
$$x_{41} + x_{42} + x_{43} + x_{44} + x_{45} \le 20y_4$$
$$x_{51} + x_{52} + x_{53} + x_{54} + x_{55} \le 20y_5$$
$$y_1 \in \{0,1\},\ y_2 \in \{0,1\},\ y_3 \in \{0,1\},\ y_4 \in \{0,1\},\ y_5 \in \{0,1\}$$
$$x_{ij} \ge 0 \text{ for all } i = 1,\ldots\ldots,5 \text{ and } j = 1,\ldots\ldots,5$$

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The Capacitated Plant Location Model Solution

- When solved, we obtain the following optimal solution:

$$y_2 = 1,\ y_4 = 1,\ y_5 = 1$$
$$x_{21} = 12,\ x_{22} = 8,\ x_{43} = 4,$$
$$x_{44} = 16,\ x_{53} = 10,\ x_{55} = 7$$

All other variables are equal to zero.

Note: There is excess capacity in Africa of 3 million units.

The cost (minimum) is $23,751.

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The Impact of Uncertainty on Network Design

- Supply chain design decisions involve significant investments in the number and size of plants to build, number of trucks, number of warehouses to acquire and whether to buy of lease these
- These decisions cannot be easily changed in the short-term and thus should be as accurate as possible
- There is 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

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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

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Discounted Cash Flow Analysis

$$\text{Discount factor} = \frac{1}{1+k}$$

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

where

$C_0, C_1, \ldots, C_T$ is a stream of cash flows over T periods

NPV = the net present value of this stream of cash flows

k = rate of return (discount rate, hurdle rate, opportunity cost of capital)

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

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NPV Example: Trips Logistics

- **Example 2**
  - The GM of Trips Logistics must decide the amount of space to lease for the upcoming three-year period. He has forecasted that Trips Logistics will incur a demand of 100,000 units for each of the three years. Trips Logistics requires 1,000 sq. ft. of space for every 1,000 units of demand. Trips Logistics receives a revenue of $1.22 per unit of demand. The three-year lease costs $1 per sq. ft./year and the spot market rate is $1.20 per sq. ft./year for each of the three years. Trips Logistics has a discount rate, $k = 0.10$. Should the GM sign a three-year lease or obtain warehousing space on the spot market?

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NPV Example: Trips Logistics

- **Solution**

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

$$NPV(\text{no lease}) = C_0 + \frac{C_1}{1+k} + \frac{C_2}{(1+k)^2}$$
$$= 2000 + \frac{2000}{1.10} + \frac{2000}{1.10^2} = \$5{,}471$$

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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

$$NPV(\text{no lease}) = C_0 + \frac{C_1}{1+k} + \frac{C_2}{(1+k)^2}$$
$$= 22000 + \frac{22000}{1.10} + \frac{22000}{1.10^2} = \$60{,}182$$

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

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Presence of Uncertainty

- In the Trips Logistics example, the manager considered both the future demands and spot market prices to be predictable
- In reality, demand and prices are highly uncertain and are likely to fluctuate during the life of any supply chain decision
- For a global supply chain, exchange rates and inflation rates are also likely to vary over time in different locations

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Representations of Uncertainty

- There are several models that can be used to represent uncertainty in factors such as demand, price and exchange rates. Let us consider an example using the binomial process.

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Binomial Representation of Uncertainty

- The binomial representation is based on the assumption that 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
- In the commonly used **multiplicative binomial**, the underlying factor moves up by a factor $u > 1$ with probability p, or down by a factor $d < 1$ with probability $1\text{-}p$
- Assuming a price P in period 0, for the multiplicative binomial, the possible outcomes for the next four periods are:
  - 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

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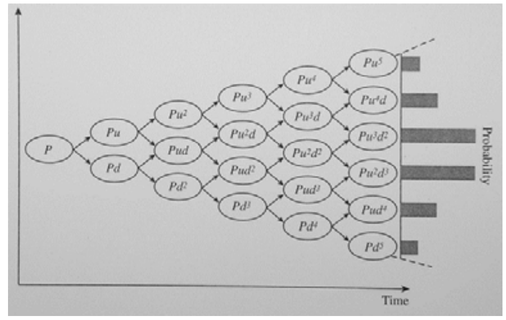
Binomial Representation of Uncertainty

- In general, for multiplicative binomial, period T has all possible outcomes $Pu^t d^{(T-t)}$, for t = 0,1,…,T
- From state $Pu^a d^{(T-a)}$ in period t, the price may move in period t+1 to either
  - $Pu^{a+1} d^{(T-a)}$ with probability p, or
  - $Pu^a d^{(T-a)+1}$ with probability (1-p)
- As the number of periods increases, the probability distribution among the end states becomes smoother and begins to resemble the normal distribution (see this as a binomial tree shown in figure)

Multiplicative Binomial Tree



Binomial Representation of Uncertainty

- In the **additive binomial**, the underlying factor increases by u in a given period with probability p and decreases by d with probability 1-p
- For the additive binomial, the states in the following four 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) contract and a short-term (or more flexible) contract (for space etc.)
- 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 the 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 Example: Trips Logistics

- **Example 3**
  - The GM of Trips Logistics must decide whether to lease warehouse space or not for the coming three years and the quantity to lease. The manager anticipates uncertainty in demand and spot prices over the next three years. Long-term lease is currently 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 requires 1,000 sq. ft. of space for every 1,000 units of demand. The current demand is 100,000 units per year. Considering multiplicative binomial uncertainty, the demand can go up by 20% with p = 0.5 or down by 20% with 1-p = 0.5 from one year to the next. The lease cost is $1

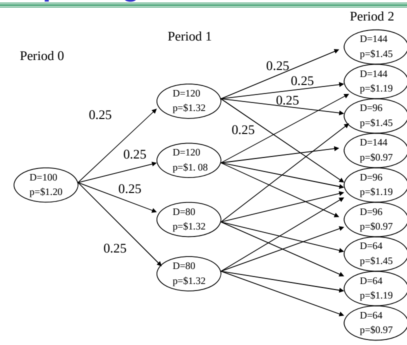
Decision Tree Methodology Example: Trips Logistics

per sq. ft./year and the current spot market rate is \$1.20 per sq. ft./year. The spot prices can go up by 10% with p = 0.5 or down by 10% with 1-p = 0.5 from one year to the next. All the probabilities given here remain unchanged from one year to the next. It is assumed that the prices of warehouse space and the demand for the product fluctuate independently. Trips Logistics receives a revenue of \$1.22 per unit of demand and uses a discount rate, k = 0.10 for each of the three years.

Which of the following three options should be chosen:

- » 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 Decision Tree



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 example:

    For D=144, p=\$1.45, in Period 2:

    $C(D$=144, p=1.45, 2) = 144,000 x 1.45 = \$208,800

    $R(D$=144, p=1.45, 2) = 144,000 x 1.22 = \$175,680

    $P(D$=144, p=1.45, 2) = 175,680 - 208,800 = -\$33,120
  - Profits at other nodes are shown in the Table below

Trips Logistics Example

Node	***Profit P(D= , p= , 2)***
(D=144, p=1.45, 2)	-\$33,120
(D=144, p=1.19, 2)	\$4,320
(D=144, p=0.97, 2)	\$36,000
(D=96, p=1.45, 2)	-\$22,080
(D=96, p=1.19, 2)	\$2,880
(D=96, p=0.97, 2)	\$24,000
(D=64, p=1.45, 2)	-\$14,720
(D=64, p=1.19, 2)	\$1,920
(D=64, p=0.97, 2)	\$16,000

Trips Logistics Example

- Expected profit at each node in Period 1 is the profit during Period 1 plus the present value (at Period 1) 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
- $P(D$=, p=,1), the total expected profit, is the sum of the profit in Period 1 and the present value of the expected profit in Period 2

Trips Logistics Example

- 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 x $P(D$=144, p=1.45, 2) +
0.25 x $P(D$=144, p=1.19, 2) +
0.25 x $P(D$=96, p=1.45, 2) +
0.25 x $P(D$=96, p=1.19, 2)

= 0.25x(-33,120)+0.25x4,320+0.25x(-22,080)+0.25x2,880

= -\$12,000

Trips Logistics Example

- The present value of this expected value in Period 1 is
  PVEP(*D*=12, *p*=1.32, 1) = *EP*(*D*=120, *p*=1.32, 1) / (1+*k*)
  = -$12,000 / (1+0.10)
  = -$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 plus the present value of future expected profits possible from this node
  P(*D*=120, *p*=1.32, 1) = [(120,000 x 1.22)-(120,000 x 1.32)] + *PVEP*(*D*=120, *p*=1.32, 1)
  = -$12,000 + (-$10,909) = -$22,909
- The total expected profit for the other nodes in Period 1 are shown in the following Table

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Trips Logistics Example

Node	Profit *P(D= , p= , 1)*
(*D*=120, *p*=1.32, 1)	-$22,909
(*D*=120, *p*=1.08, 1)	$32,073
(*D*=80, *p*=1.32, 1)	-$15,273
(*D*=80, *p*=1.08, 1)	$21,382

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Trips Logistics Example

- 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 x *P*(*D*=120, *p*=1.32, 1) +
  0.25 x *P*(*D*=120, *p*=1.08, 1) +
  0.25 x *P*(*D*=96, *p*=1.32, 1) +
  0.25 x *P*(*D*=96, *p*=1.08, 1)
  = 0.25x(-22,909)+0.25x32,073+0.25x(-15,273)+0.25x21,382
  = $3,818
  PVEP(*D*=100, *p*=1.20, 0) = *EP*(*D*=100, *p*=1.20, 0) / (1+*k*)
  = $3,818 / (1 + 0.10) = $3,471

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Trips Logistics Example

P(D=100, *p*=1.20, 0) = 100,000x1.22-100,000x1.20 + *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**

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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
- The manager would prefer to sign the three-year lease for 100,000 sq. ft. because this option has the higher expected profit

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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 (**net profit is $46,725** because of the $10,000 upfront payment)
- 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 flexible option has an expected present value $8,361 (46,725-38,364) greater than the inflexible lease option (including the upfront $10,000 payment)

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