What is a supply chain?

A supply chain consists of all parties involved, directly or indirectly, in fulfilling a customer request. The supply chain includes not only the manufacturer and suppliers, but also transporters, warehouses, retailers, and even customers themselves.

What is the objective of a supply chain?

The objective of every supply chain is to maximize the surplus or overall value generated.

What are the three key supply chain decision phases and their significances?

The three key supply chain decision phases are as follows:

- **Supply chain strategy or design**: This represents the long range decision phase and involves decisions about the structure of the supply chain and what processes each stage will perform.
- **Supply chain planning**: This phase involves setting of policies that govern medium term operations. Of course, they are guided by the configuration from the design phase.
- **Supply chain operation**: Here the time horizon is weekly or daily and during this phase decisions regarding individual customer orders are emphasized. At this level, supply chain configurations are considered fixed and planning policies are already defined. The goal is to implement the operating policies such that the incoming customer orders are handled as effectively as possible.

What are the cycle and push/pull views of a supply chain?

A cycle view of a supply chain divides processes into cycles, each performed at the interface between two successive stages of a supply chain. Each cycle starts with an order placed by one stage of the supply chain and ends when the order is received from the supplier stage. A push/pull view of a supply chain characterizes processes based on their timing relative to that of a customer order. Pull processes are performed in response to a customer order, whereas push processes are performed in anticipation of customer order.

How can supply chain macro processes be classified?

All supply chain processes can be classified into three macro processes based on whether they are at the customer or supplier or are internal to the firm. The CRM (Customer Relationship Management) macro process consists of all processes at the interface between the firm and the customer that work to generate, receive, and track customer orders. The ISCM (Internal Supply Chain Management) macro process consists of all supply chain processes that are internal to the firm and work to plan for and fulfill customer orders. The SRM (Supplier Relationship Management) macro process consists of all supply chain processes at the interface between the firm and its suppliers that work to evaluate and select supplies and then source goods and services from them.

Why is achieving strategic fit critical to a company's overall success?

A lack of strategic fit between the competitive and supply chain strategy can result in the supply chain taking actions that are not consistent with customer needs, leading to a reduction in supply chain surplus and decreasing supply chain profitability. Strategic fit requires that all functions within a firm and stages in the supply chain target the same goal, one that is consistent with customer needs.

How does a company achieve strategic fit between its supply chain strategy & its competitive strategy?

To achieve strategic fit, a company must first understand the needs of the customers being served, understand the uncertainty of the supply chain, and identify the implied uncertainty. The second step is to understand the supply chain's capabilities in terms of efficiency and responsiveness. The key to strategic fit is ensuring that supply chain responsiveness is consistent with customer needs, supply capabilities, and the resulting implied uncertainty.

What are the major drivers of supply chain performance?

There are three logistical drivers (viz., facilities, inventory and transportation) and three cross-functional drivers (viz., information, sources and pricing) that determine the performance of any supply chain. These drivers interact with each other to determine the supply chain's performance in terms of responsiveness and efficiency.

What is the role of each driver in creating strategic fit between supply chain strategy and competitive strategy?

A company achieving strategic fit has found the right balance between responsiveness and efficiency. Each driver affects this balance. Having more facilities generally makes a chain more responsive, while having fewer central facilities creates higher efficiency. Holding higher levels of inventory increases the responsiveness of a supply chain, while keeping inventory low increases the chain's efficiency. Using faster modes of transportation increases a chain's responsiveness, while using slower modes generally increases efficiency. Investing in information can vastly improve the supply chain performance on both dimensions. The investment, however, must be made on the strategic position supported by the other drivers. Appropriate sourcing decision raise supply chain profits by assigning supply chain functions to the right party, who brings higher economy of scale or a higher level of aggregation of uncertainty. Pricing can be used to attract customers who value responsiveness as well as customers who want efficiency. The supply chain can then be structured to provide responsiveness to some customers while improving overall efficiency.

What are the major obstacles to achieving strategic fit?

Increasing product variety, decreasing product life cycles, demanding customers, and global competition all make creating supply chain strategies more difficult, as these factors can hamper supply chain performance. The increase in globalization of the supply chain and fragmentation of supply chain ownership has also made it more difficult to execute supply chain strategies.

Method of Estimating Trend

- **Moving Average**

$$N\ period\ moving\ average = Summation\ of\ N\ Data\ point/Number\ of\ Periods, N$$

Method of choosing the best Moving average (data from class question)

There are a few disadvantages of using this method of estimating trend:

- There is no equation
- It loses data and can be strongly affected by extreme values because all past data is weighed equally

Moving Average	Noise Dampening Ability	Impulse Response	Precision
3 Week	Low	High	Low
5 Week	Mid	Mid	High
7 Week	High	Low	Mid

- **Exponential Smoothing**

This is a type of moving average forecasting technique which weighs past data in an exponential manner so that the most recent data carries more weight in the moving average

$$F(t) = F(t-1) + \alpha[D(t-1) - F(t-1)]$$
$$= A_0 D(t-1) + A_1 D(t-2) + A_2 D(t-3) + \cdots + A_{n-1} D(t-n)$$
= old forecast + α (error in old forecast)

Where,
$F(t)$ = current period forecast
$F(t\text{-}1)$ = last period forecast
α = smoothing constant (a number between 0 and 1)
$D(t\text{-}1)$ = last period demand
$A_i = \alpha(1-\alpha)^i$, *Sum of all A_i's should be 1*

Deseasonalized is synonymous with ***Trend*** | ***Seasonalized*** is synonymous with ***Actual***

➢ *The following data is given:*
January trend forecast = 400 units |Actual sales in January = 344 units
Actual sales in February = 414 units | Seasonal index for January = 0.8
Seasonal index for February = 0.9 | Seasonal index for March = 1.2 | α = 0.1

Use exponential smoothing to find the forecast (seasonalized) for March?

Exponential Smoothing Example Solution

Deseasonalize Demand in January = 344/0.8 = 430 units

Compute February deseasonalized (trend) forecast = $F(t) = F(t-1) + \alpha[D(t-1) - F(t-1)]$
= 400 + 0.1*(430-400) = 403 Units

Although not required, one can calculate the
Seasonalized (actual) forecast of February = 403 x 0.9 = 363 units
Deseasonalize February Demand: 414/0.9 = 460 units

Compute March deseasonalized (trend) forecast = $F(t) = F(t-1) + \alpha[D(t-1) - F(t-1)]$
= 403 + 0.1 * (460-403) = 409 Units

Calculate Seasonalized (actual) forecast for March = 409 x 1.2 = ***491 units***

- **Method of Least Squares**

This is one of the most widely used methods

It yields a "line of best fit". It could be linear or nonlinear. If it is linear, it is of the following form:

$Y = a + bX$

Associated with this equation are the following Normal Equations, Which help in calculating the coefficients *a* & *b*.

$\sum Y = Na + b\sum X \mid \sum XY = Na + b\sum X$

$b = \frac{(N\sum XY - \sum X \sum Y)}{N\sum X^2 - (\sum X)^2} \mid a = \left(\frac{\sum Y}{N}\right) - b\left(\frac{\sum X}{N}\right)$

Standard Error of Forecast

$S_{YX} = \sqrt{(\sum Y^2 - a\sum Y - b\sum XY)/(N-2)}$

Upper Limit $= Y_t + t * S_{YX}$

Lower Limit $= Y_t - t * S_{YX}$

Year	Quantity				Total
	I	II	III	IV	
1	43	27	10	22	102
2	49	35	14	27	125
3	58	47	14	32	151
4	71	53	18	35	177
5	80	63	22	41	206
Total	301	225	78	157	761
Q. Avg.	60.2	45.0	15.6	31.4	38.50
S.I.	1.582	1.183	0.410	0.825	

Assuming Linear growth and deseasonalizing the data, we get the following:

Note: *Deseasonlized* values are calculated by dividing Y values by Seasonal Indices.

Substituting the above values in the normal equations and solving for a & b, we get $a = 21.58$, $b = 1.57$

Hence, $Y = a + bt = 21.58 + 1.57t$

Year/Otr	t	Y	Y_D	$Y_d * t$	t^2
1/I	1	43	27.18	27.18	1
1/II	2	27	22.83	45.66	4
1/III	3	10	24.39	73.17	9
1/IV	4	22	26.66	106.64	16
2/I	5	49	30.97	154.85	25
2/II	6	35	29.59	177.57	36
2/III	7	14	34.15	239.03	49
2/IV	8	27	32.72	261.75	64
3/I	9	58	36.66	329.94	81
3/II	10	47	39.74	397.41	100
3/III	11	14	34.15	375.62	121
3/IV	12	32	38.78	465.32	144
4/I	13	71	44.88	583.39	169
4/II	14	53	44.81	627.40	196
4/III	15	18	43.90	658.56	225
4/IV	16	35	42.41	678.60	256
5/I	17	80	50.56	859.60	289
5/II	18	63	53.27	958.86	324
5/III	19	22	53.66	1019.54	361
5/IV	20	41	49.68	993.66	400
Total	210		761	9033.76	2870

Forecast for ***Year 6***,
Quarter I = (21.58 + 1.57 * 21)*1.582 = 86.73
Quarter II = (21.58 + 1.57 * 22)*1.183 = 65.66
Quarter III= (21.58 + 1.57 * 23)*0.410 = 23.65
Quarter IV = (21.58 + 1.57 * 24)*0.825 = 49.19

Reasons to carry Inventory

There are many reasons for carrying inventory

- Companies do not want to disappoint their customers. That is, whenever the customer demands something, they want to be able to supply it. (to reduce opportunity loss)
- In case of raw material, if we run out of some item it could hamper production. Even if we were assembling large products, running out of even a small item like a nut or a bolt could shut down an assembly line.

Purpose of Inventory

- Inventory is an aid to continuous production.
- If we were not allowed to carry inventory, there might be times when we might have to stop production due to some interruption in delivery of items.

How much to order (It is a function of costs): This depends on many factors, e.g. how much space do we have? Or how much money do we have? Or how much is the carrying cost? Or how much is the ordering cost?

When to order (It is a function of forecast or scheduled requirements): That is, what is the order cycle?

Ordering and setup costs: This is the cost associated with placing orders or with setting up the machine (getting ready) to build inventory

Carrying costs: Costs of carrying items in inventory which might include cost of the space used, interest charges on the money blocked in inventory, etc.

Purchase cost: Cost of the item itself

Types of Inventory: Raw Stock Inventory | Work-In-Process Inventory | Final Product Inventory

Production Line & buffer Inventory

d_i = downtime percentage for the i^{th} stage | b_{ij} = Buffer stock between i^{th} stage & j^{th} stage
O_i = Output (in percentage of time) from i^{th} stage

- If $bij = 0 \mid O1 = (1 - d1) \mid O2 = (1 - d1)(1 - d2) \mid O3 = (1 - d1)(1 - d2)(1 - d3)$
  If $d1$ = 5%, $d2$ = 10%, $d3$ = 2%,
  $O1$ = (1 – 0.5) = 0.95 = 95% | $O2$ = 85.5% | **O3 = 83.8%**
- If $bij = \infty \mid O1 = 1 - d1 \mid O2 = 1 - d2 \mid O3 = 1 - d3$
  If $d1$ = 5%, $d2$ = 10%, $d3$ = 2%,
  $O1$ = (1 – 0.05) = 0.95 = 95% | $O2$ = (1– 0.1) = 90% | **O3** = (1–0.02) = **98%**

This is a lot of improvement over the "no buffer" case. In reality, however, there is a limit on buffer inventory.

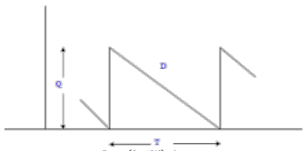
ABC Classification

Category **A items** include roughly **10-20%** of items that typically account for **70-80%** of total dollar value
Category **B items** include roughly **30-40%** of items that typically account for **15-20%** of total dollar value
Category **C items** include roughly **40-50%** of items that typically account for **5-10%** of total dollar value

EOQ Model

Nomenclature

Q = Order quantity | T = Time between orders (cycle time)
D = Demand rate or depletion rate | P = Ordering cost
I = Interest charges/unit of inventory/unit time
W = warehousing cost/unit of inventory/unit time
H = Overall inventory cost factor
C = Cost/item (capital investment cost) | TC = Total cost/unit



Multiple Product Case: $TC_M = C + \frac{P}{Q} + \frac{(I+W)*Q}{2D}$ | Single Product Case: $TC_S = C + \frac{P}{Q} + \frac{(I+2W)*Q}{2D}$

$Q_M = \sqrt{\frac{2DP}{I+W}}$ | $Q_S = \sqrt{\frac{2DP}{I+2W}}$ | $Q = \sqrt{\frac{P}{H}}$ | $H_M = \frac{I+W}{2D}$ | $H_S = \frac{I+2W}{2D}$ | $TC = C + \frac{P}{Q} + HQ$

Question

Given, P = \$85/order, i = 25%/year, I = 0.25 * 200 = \$50/unit-year, C = \$200/unit, D = 3000 units/year and W = \$2/unit-month = \$24/unit-year,

$EOQ_S = \sqrt{\frac{2DP}{I+2W}} = 72\ Units \mid TC = C + \frac{P}{Q} + H_s * Q,\ Inventory\ Cost/Unit\ = \frac{P}{Q} + H_s * Q$

Annual Inventory Cost = $\frac{P}{Q} + H_s * Q = 7068.95$ | Ordering Cycle = $\frac{Q}{D} = \frac{72}{3000} = 0.024\ Year$

$EOQ_M = \sqrt{\frac{2DP}{I+W}} = 83\ Units \mid TC = C + \frac{P}{Q} + H_M * Q,\ Inventory\ Cost/Unit\ = \frac{P}{Q} + H_M * Q$

Annual Inventory Cost = $\left(\frac{P}{Q} + H_m * Q\right) * D = 6143.29$ | Ordering Cycle = $\frac{Q}{D} = \frac{83}{3000} = 0.028\ Year$

EMQ Model

Nomenclature: A = Arrival rate | T_A = Arrival time (manufacturing time) | ss = Startup Level (Safety Stock)

$D = \frac{Q}{T} \Big| A = \frac{Q}{T_A} \Big| ss = D * T_A = \frac{DQ}{A} \mid Q_M = \frac{T - T_A}{T} * Q$

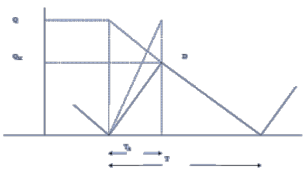
- When Item Produced is immediately available:

$Avg.Invetory = \frac{Q_M}{2} \mid Max.Inventory = Q_M = \left(1 - \frac{D}{A}\right) * Q$

$TC_M = C + \frac{P}{Q} + \frac{(I+W)*\left(1-\frac{D}{A}\right)*Q}{2D}$

$TC_s = C + \frac{P}{Q} + \frac{(I+2W)*\left(1-\frac{D}{A}\right)*Q}{2D}$

$Q_M = \sqrt{\frac{2PD}{(I+W)\left(1-\frac{D}{A}\right)}} \mid Q_s = \sqrt{\frac{2PD}{(I+2W)\left(1-\frac{D}{A}\right)}}$



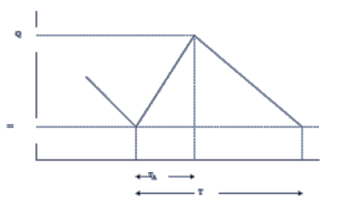
- When Item Produced is NOT immediately available:

$Avg.Invetory = \frac{Q + ss}{2} \mid Max.Inventory = Q$

$TC_M = C + \frac{P}{Q} + \frac{(I+W)*\left(1+\frac{D}{A}\right)*Q}{2D}$

$TC_s = C + \frac{P}{Q} + \frac{(I+2W)*\left(1+\frac{D}{A}\right)*Q}{2D}$

$Q_M = \sqrt{\frac{2PD}{(I+W)\left(1+\frac{D}{A}\right)}} \mid Q_s = \sqrt{\frac{2PD}{I\left(1+\frac{D}{A}\right)+2W}}$



Questions: This is a SS case for multiple products.

Given, P = \$200/order, I = \$5/unit-year, D = 500 units/months = 6000 units/year

- A = 1500 units/month = 18000 units/year and W = \$10/unit-year,

$EMQ_M = \sqrt{2PD/\left((I+W)\left(1+\frac{D}{A}\right)\right)} = 346\ Units \mid \frac{Inventory\ cost}{Unit-Year} = \frac{P}{Q} + \frac{(I+W)\left(1+\frac{D}{A}\right)}{2D} = \$1.15$

- Safety stock has to be carried out in the above previous model, EMQ remains the same but inventory cost is increased. $Safety\ Stock\ = \ D\ units\ /months\ * 0.2\ months\ = \ 500 * 0.2\ = 100\ Units$
  Inventory cost of Safety Stock = $(I+W)$*ss/D = (5+10)*100/6000 = \$0.25.
  Hence the Total Inventory cost/unit-year = 1.15 + 0.25 = \$1.40.

Material Requirements Planning

It is a technique for determining when to order dependent demand items and how to reschedule orders to adjust to changing requirements

MRP Lot Sizing Procedures

Lot for Lot (LFL) | Economic Order Quantity (EOQ) | Period Order Quantity (POQ) | Part Period Balancing (PPB)

LFL procedure is order quantity is equal to necessary quantity for the next period

$EOQ\ units = \sqrt{\frac{2*D_{avg}*P}{W}}\ units \mid POQ\ periods = \frac{EOQ}{D_{Avg}} = \sqrt{\frac{2*P}{W*D_{avg}}}\ periods$

PPB = consider tentative lot size until the cumulative extra carrying cost crosses the Purchase order/setup cost and find extra inventory (left over inventory) in the period. Calculate the cumulative extra carrying cost based on the periods over which the extra inventory is carried over and use the optimal value which is closer to the Purchase Order cost as the optimal PPB. PPB is not constant as it is calculated for every order separately.

Examples for Calculation:

Lead Time = 1
Lot Size = 119
Lot Sizing Rule = EOQ

		Period					
		1	2	3	4	5	6
Projected Requirement		40	20	10	60	10	30
Scheduled Receipts					119		
On Hand at end of Period	80	40	20	10	69	59	29
Planned order Release				119			

Lead Time = 1
Lot Size = 4 Weeks
Lot Sizing Rule = POQ

		Period					
		1	2	3	4	5	6
Projected Requirement		20	10	30	50	70	40
Scheduled Receipts				180			
On Hand at end of Period	40	20	10	160	110	40	0
Planned order Release			180				

Lead Time = 0
Lot Sizing Rule = PPB

		Period											
		1	2	3	4	5	6	7	8	9	10	11	12
Projected Requirement		124	6	316	183		55	43	154			114	171
Scheduled Receipts		500			281				268				171
On Hand at end of Period	0	376	316	0	98	98	43	0	114	114	114	0	0
Planned order Release		500			281				268				171

Order Arrives in Period #	Tentative Lot Size	Extra Inventory	No. of Periods held	Extra Carrying Cost	Cumulative Extra Carrying Cost	Is this > Setup Cost (100)?
1	124	0	0	0	0	No
	184	60	1	12.60	12.6	No
	500	316	2	132.72	**145.32**	Yes
4	183	0	0	0	0	No
	183	0	1	0	0	No
	238	55	2	23.1	23.1	No
	281	43	3	27.09	**50.19**	No
	435	154	4	129.36	179.55	Yes
And so on….						

Aggregate Planning in a Supply Chain

- Aggregate planning consists of efforts to plan a desired output over the longer range by adjusting the production rate, employment, inventory, and other controllable variables
- These controllable variables in effect constitute pure strategies by which fluctuations in demand and uncertainities in production activities can be accommodated
- The objective of aggregate planning is the productive utilization of both human and equipment resources

Stable work force but permit idle time when demand is slack and goes overtime when demand is strong

- Idle time is obviously a waste and overtime and shift work usually command a premium

Constant work force and level production but carry sufficiently large amounts of inventory to absorb all demand fluctuations

- This could be an expensive proposition as it involves costs such as carrying costs, storage costs, taxes and obsolescence costs

Backorder Strategy

- It assumes that the customers are willing to wait for delivery and this effectively smoothes out production
- Otherwise this strategy results in stock out costs because some customers will seek out other suppliers
- In essence, this is the strategy of negative inventory

Subcontracting Strategy

- Permits level production pushing the fluctuations off into subcontracting
- Subcontracting costs are higher than in-house production

Plant capacity

- This is not a short term project
- Often requires major capital expenditure

Question:
Given: Initial Inventory = 4
Final Inventory required = 3
Regular time production cost = \$10/unit
Overtime production cost = \$12/unit
Carrying cost = \$3/unit-period
Backordering cost = \$4/unit-period

	Per. 1	Per. 2	Per. 3	Final Inv.	Slack	Capacity
Initial Inv.	0	3	6	9	0	4
Per. 1 RT	10	13	16	19	0	2
Per 1 OT	12	15	18	21	0	5
Per 2 RT	14	10	13	16	0	1
Per 2 OT	16	12	15	18	0	3
Per 3 RT	18	14	10	13	0	9
Per 3 OT	20	16	12	15	0	2
Demand	4	9	2	3	8	26 26

Period	Regular Time Capacity	Overtime Capacity	Demand
1	2	5	4
2	1	3	9
3	9	2	2

Transportation

Factors Affecting Transportation Decisions:

- Shipper → Transportation Cost, Inventory Cost, Facility Cost
- Carrier → Vehicle Related Cost, Fixed Operating Cost, Trip Related Cost

Network Structure	Pros	Cons
Direct Shipping	• No intermediate warehouse • Simple to coordinate	• High inventories (due to large lot size) • Significant receiving expense
Direct Shipping with Milk Runs	• Lower transportation cost for small lots • Lower inventories	• Increased coordination complexity
All Shipments via Central DC with Inventory Storage	• Lower inbound transportation cost through consolidation	• Increased inventory cost • Increased handling at DC
All Shipping via Central DC with inventory Storage	• Very low inventory requirement • Lower transportation cost through consolidation	• Increased coordination complexity
Shipping via DC using Milk Runs	• Lower outbound transportation cost for small lots	• Further increase in coordination complexity
Tailored Network	• Transportation choice that best matches the needs of individual product and buyer	• Highest coordination complexity

Modes of Transportation:

- Trucks → Truck Load (TL) | Less than Truck Load(LTL)
- Rail | Air | Package Carriers | Water | Pipeline | Intermodal

Transportation Network:

Question:

Stores: 8 | Supply Source: 4 | Products: 4 | Truck Capacity: 40,000 Units
Cost/Load: \$1000 | Cost/Delivery: \$100 | Inventory @Store: \$0.2/Unit/Year
Direct Shipments or Milk Runs for 960,000 units & 120,000 units

Demand	**960000**			**120000**		
Milk Runs	One Store	Two Store	Four Stores	One Store	Two Store	Four Stores
Batch Size/ Store	40,000	20,000	10,000	40,000	20,000	10,000
# of Shipments	24	48	96	3	6	12
Trucking Cost (#Ship*Cost*4*8)	\$844,800	\$921,600	\$1,075,200	\$105,600	\$115,200	\$134,400
Avg. Inventory	20,000	10,000	5,000	20,000	10,000	5,000
Inventory Cost (Avg. Inventory*0.2*4*8)	\$128,000	\$64,000	\$32,000	\$128,000	\$64,000	\$32,000
Total Cost	**\$972,800**	\$985,600	\$1,107,200	\$233,600	\$179,200	**\$166,400**

Cycle inventory is the average inventory that builds up in the supply chain because a supply chain stage either produces or purchases in lots that are larger than those demanded by the customer

Cycle service level (CSL) is the fraction of replenishment cycle that meets all customer demand

Safety inventory is the inventory carried for the purpose of satisfying demand that exceeds the amount forecasted in a given period

Average inventory is therefore cycle inventory plus safety inventory

Carrier	*Qty Range (cwt)*	*Cost (\$/cwt)*
AM Railroad	200+	6.50
Northeast Trucking	100+	7.50
Golden Freightways	50-150	8.00
Golden Freightways	150-250	6.00
Golden Freightways	250+	4.00

Choice of Transportation Mode:

Question

Demand: 120,000 Motors | Cost: \$120/Motor
SS: 50% of Avg Demand during Lead Time LT: 1day+Transportation | I: \$30
1cwt = 100Lbs = 10 Motors
Total Cost of Motors = \$14, 400, 000

	AM	NE	Golden
Transportation Time	5	3	3
In-Transit Inventory(D*TT/365)	1644	986	986
Lead Time	6	4	4
Safety Inventory (D/365)*(LT/2)	986	658	658

	AM Railroad	Northeast Trucking	**Golden Freightways**					
No. of Motor	**2000**	**1000**	**500**	**1500**	**2500**	**3000**	**4000**	**4000**
Cycle Inventory	1000	500	**250**	750	1250	1500	2000	2000
Safety Inventory	986	658	**658**	658	658	658	658	658
In-Transit Inventory	1644	986	**986**	986	986	986	986	986
Invetory Cost	108900	64320	**56820**	71820	86820	94320	109320	109320
Transportation Cost	78000	90000	**96000**	96000	86400	80000	72000	67500
Total	186900	154320	**152820**	167820	173220	174320	181320	176820

Inventory Aggregation

Given:

Current Situation

Transport Charges via UPS: $0.66+$0.26x

Inventory Holding Cost: 25% of Cost |

24 Territories | LT: 1W | T: 4W |CSL = 0.997| $F^{-1}(CSL) = z = 2.75$ | U=Units

	Weight	Cost	Demand μ	Demand σ
Highval Products	0.1	$200	2	5
Lowval Products	0.04	$30	20	5

Inventory Cost

	Highval	Lowval
Average Lot Size, $Q_H = T * \mu_H$	8U	80U
Safety Inventory, $SS_H = z * \sqrt{T+L} * \sigma_H$	30.75U	30.75U
Total Inventory, QH/2+SSH	34.75U	70.75U
Total (across all 24 Territories)	833.90	1697.90
Inventory Holding Cost	$41,695	$12,734
Total Cost	$54,429	

Transportation Cost

	Highval	Lowval	Total
Average weight of each replenishment order, x	0.8	3.2	4
Shipping Cost via UPS	$0.66+$0.26∗x		$1.70
Annual Transportation Cost (24 Territories, 13 Orders)			$530.40

Total Cost (Inventory +Transportation)	$54,960

Option A: Transport Charges via UPS: $0.66+$0.26x Inventory Holding Cost: 25% of Cost | 24 Territories

LT: 1W | T: 4W |CSL = 0.997| $F^{-1}(CSL) = z = 2.75$ | U=Units

Inventory Cost

	Highval	Lowval
Average Lot Size, $Q_H = T * \mu_H$	2U	20U
Safety Inventory, $SS_H = z * \sqrt{T+L} * \sigma_H$	19.4U	19.4U
Total Inventory, QH/2+SSH	20.4U	29.4U
Total (across all 24 Territories)	490	706
Inventory Holding Cost	$24,500	$5,295
Total Cost	$29,795	

Transportation Cost

	Highval	Lowval	Total
Average weight of each replenishment order, x	0.2	0.8	1
Shipping Cost via UPS	$0.66+$0.26∗x		$0.92
Annual Transportation Cost (24 Territories, 13 Orders)			$1,148

Total Cost (Inventory +Transportation)	$30,943

Option B: Transport Charges via FedEx: $5.53+$0.53x Inventory Holding Cost: 25% of Cost | 24 Territories

LT: 1W | T: 4W |CSL = 0.997| $F^{-1}(CSL) = z = 2.75$ | U=Units

Inventory Cost

	Highval	Lowval
Average Lot Size, $Q_H = T * \mu_H$	48U	480U
Safety Inventory, $SS_H = z * \sqrt{T+L} * \sigma_H$	95.26U	95.26U
Total Inventory, QH/2+SSH	119.26U	335.26U
Total (in Madison)	119.26U	335.26U
Inventory Holding Cost	$5,963	$2,514
Total Cost	$8,478	

Transportation Cost

	Highval	Lowval	Total
Average weight of each replenishment order, x	0.1	0.4	0.5
Shipping Cost via UPS	$5.53+$0.53x		$5.80
Annual Transportation Cost (52Weeks, 24 Territories, 2Orders/Territory)			$14, 464

Total Cost (Inventory +Transportation)	**$22,942**

Optimal Pricing to Maximize Profit:

$c = Cost/Unit$ | $p = Selling\ Price/Unit$

Demand = $A - Bp$ | Revenue = $p * (A - Bp)$ | Cost = $c * (A - Bp)$

Profit = $(p - c) * (A - Bp) = (Ap - Bp^2 - Ac + Bcp)$ | $\frac{d\,(Profit)}{dp} = 0 \Rightarrow Selling\ Price,\ p = \left(\frac{A}{2*B}\right) + \frac{c}{2}$

Supplier Assessment Factors:

Replenishment Lead Time | On-Time Performance | Supply Flexibility |
Delivery Frequency /Minimum Lot Size | Supply Quality | Inbound Transportation Cost |
Pricing Terms | Information Coordination Capability | Design Collaboration Capability |
Exchange Rates, Taxes, Duties | Supplier Viability

Handling Double Uncertainty

$D_L = D * L$ & $\sigma_L = \sqrt{L * \sigma_D^2 + D^2 * s_L^2}$

D is the average demand/period | σ_D is the standard deviation of demand per period

L is the average lead time for replenishment | s_L is the standard deviation of the lead time

Question

Local Supplier = $1.00/bearing | Lead Time = 2 Weeks | Batch Size = 2,000 | SD = 1 Week

New Supplier = $0.97/bearing | Lead Time = 6 Weeks | Batch Size = 8,000 | SD = 4 Weeks

Inventory Holding Cost = 25%

CSL = 95%

Mean Demand, μ_D = 1,000

SD, σ_D = 300

	Local Supplier	New Supplier
Annual Cost (1000*52*C)	$52,000	$50,440
Annual Cycle Inventory(D/2)	1,000	4,000
Annual Inventory Cost (1000*C*25%)	$250	$970
SD of Demand During LT $\sigma_L = \sqrt{l * \sigma_D^2 + D^2 * s_L^2}$	1,086	4,067
Safety Inventory ($F^{-1}(CSL) * \sigma_L$)	1,788	6,693
Annual Cost of Safety Inventory (SI*C*25%)	$447	$1,623
Total Cost	**$52,697**	$53,033

Make to Stock (No Contract)

How much should the **Manufacturer** produce?

Distributor	Selling Cost/Unit	$125
	Buying Cost/Unit	$80
Manufacturer	Fixed Cost	$100,000
	Variable Cost/Unit	$55
	Selling Price to Distributor/Unit	$80
	Selling price to Discount store/unit	$20

Manufacturer Produces 12,000 Units

		Manufacturer			Distributor		
Demand	**Probability**	**Revenue**	**Cost**	**Profit**	**Revenue**	**Cost**	**Profit**
8000	0.11	$720,000	$760,000	-$40,000	$1,000,000	$640,000	$360,000
10000	0.11	$840,000	$760,000	$80,000	$1,250,000	$800,000	$450,000
12000	0.28	$960,000	$760,000	$200,000	$1,500,000	$960,000	$540,000
14000	0.22	$960,000	$760,000	$200,000	$1,500,000	$960,000	$540,000
16000	0.18	$960,000	$760,000	$200,000	$1,500,000	$960,000	$540,000
18000	0.1	$960,000	$760,000	$200,000	$1,500,000	$960,000	$540,000
Expected Profit		**Manufacturer**		$160,400	**Distributor**		$510,300

The Summary of the Calculations is as Follows:

Distributor's Order	Manufacturer's Profit	Distributor's Profit	Total Profit
8,000	$100,000	$360,000	$460,000
10,000	$136,800	$450,000	$586,800
12,000	**$160,400**	$510,300	$670,700
14,000	$150,400	$630,000	$780,400
16,000	$114,000	$720,000	$834,000
18,000	$56,000	**$810,000**	**$866,000**

Make to Stock (Pay-Back Contract)

Distributor	Selling Cost/Unit	$125
	Buying Cost/Unit	$80
	Pay-Back Cost/Unit	$18
Manufacturer	Fixed Cost	$100,000
	Variable Cost/Unit	$55
	Selling Price to Distributor/Unit	$80
	Selling price to Discount store/unit	$20

Manufacturer Produces 14,000 Units

		Manufacturer			Distributor		
Demand	**Probability**	**Revenue**	**Cost**	**Profit**	**Revenue**	**Cost**	**Profit**
8000	0.11	$868,000	$870,000	-$2,000	$1,000,000	$748,000	$252,000
10000	0.11	$952,000	$870,000	$82,000	$1,250,000	$872,000	$378,000
12000	0.28	$1,036,000	$870,000	$166,000	$1,500,000	$996,000	$504,000
14000	0.22	$1,120,000	$870,000	$250,000	$1,750,000	$1,120,000	$630,000
16000	0.18	$1,120,000	$870,000	$250,000	$1,750,000	$1,120,000	$630,000
18000	0.1	$1,120,000	$870,000	$250,000	$1,750,000	$1,120,000	$630,000
Expected Profit		**Manufacturer**		$180,280	**Distributor**		$525,420

The Summary of the Calculations is as Follows:

Distributor's Order	Manufacturer's Profit	Distributor's Profit	Total Profit
8,000	$100,000	$360,000	$460,000
10,000	$140,760	$436,140	$576,900
12,000	$172,280	$498,420	$670,700
14,000	**$180,280**	**$525,420**	**$705,700**
16,000	$169,800	$524,700	$694,500
18,000	$144,200	$501,300	$645,500

Make to Stock (Cost-Sharing Contract)

Distributor	Selling Cost/Unit	$125
	Buying Cost/Unit	$80
	Cost-Sharing Contract	30% of Manufacturing Cost
Manufacturer	Fixed Cost	$100,000
	Variable Cost/Unit	$55
	Selling Price to Distributor/Unit	$62
	Selling price to Discount store/unit	$20

Manufacturer Produces 14,000 Units

		Manufacturer			Distributor		
Demand	**Probability**	**Revenue**	**Cost**	**Profit**	**Revenue**	**Cost**	**Profit**
8000	0.11	$616,000	$609,000	$7,000	$1,000,000	$757,000	$243,000
10000	0.11	$700,000	$609,000	$91,000	$1,250,000	$881,000	$369,000
12000	0.28	$784,000	$609,000	$175,000	$1,500,000	$1,005,000	$495,000
14000	0.22	$868,000	$609,000	$259,000	$1,750,000	$1,129,000	$621,000
16000	0.18	$868,000	$609,000	$259,000	$1,750,000	$1,129,000	$621,000
18000	0.1	$868,000	$609,000	$259,000	$1,750,000	$1,129,000	$621,000
Expected Profit		**Manufacturer**		$189,280	**Distributor**		$516,420

The Summary of the Calculations is as Follows

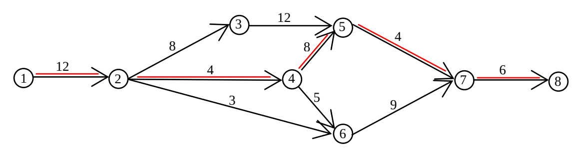
Distributor's Order	Manufacturer's Profit	Distributor's Profit	Total Profit
8,000	$118,000	$342,000	$460,000
10,000	$155,760	$416,740	$572,500
12,000	$184,280	$473,220	$657,500
14,000	**$189,280**	**$516,420**	**$705,600**
16,000	$175,800	$456,700	$632,500
18,000	$147,200	$400,300	$547,500

Scheduling

Project Planning: Critical Path Method (CPM) | Program Evaluation Review Technique (PERT)

CPM

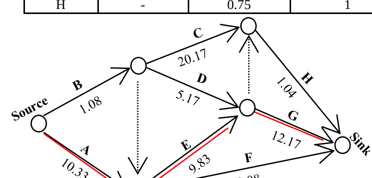
Path	Length
1-2-3-5-7-8	42
1-2-4-5-7-8	**44**
1-2-4-6-7-8	36
1-2-6-7-8	30



PERT

(If there are 2 Path that are the longest then the one with greater variance is considered as Critical Path)

Activity	Immediate Successor	Optimistic, a	Most Likely, m	Pessimistic, b	Mean, $\mu = (a + 4m + b)/$	Variance $\sigma = \left(\frac{b-a}{6}\right)^2$
A	E, F	8	10	14	10.33	1.00
B	C, D, E, F	0.5	1	2	1.08	0.06
C	H	16	20	25	20.17	2.25
D	G, H	3	5	8	5.17	0.69
E	G, H	7	10	12	9.83	0.69
F	-	0.5	2	4	2.08	0.34
G	-	8	12	17	12.17	2.25
H	-	0.75	1	1.5	1.04	0.02



	Path	Duration	Mean Duration	Standard Deviation
	A-E-H	10.33+9.83+1.04	21.21	1.31
1st	A-E-G	10.33+9.83+12.17	32.33*	1.99*
	A-F	10.33+2.08	12.42	1.16
3rd	B-C-H	1.08+20.17+1.04	22.29*	1.53*
	B-D-H	1.08+5.17+1.04	8.29	0.88
	B-D-G	1.08+5.17+12.17	7.29	1.73
	B-E-H	1.08+9.83+1.04	11.96	0.88
2nd	B-E-G	1.08+9.83+12.17	23.08*	1.73*
	B-F	1.08+2.08	3.17	0.63

Probability of the Project completing 3 *days* earlier is $Z = \frac{29.33-32.33}{1.99} = -1.507 \Rightarrow P = \mathbf{0.0668 * 100\% = 6.68\%}$

Critical Activities: A, B, E, G (These four activities are included in the first and second critical paths)

For 90% CI →Z=1.28 $\Rightarrow 1.28 = \frac{x-32.33}{1.99} \Rightarrow \boldsymbol{x = 34.87\ days}$

Brook's Algorithm (Longest Duration | Largest Resource | Alphabetic)

Activity	**A**	**B**	**E**	**C**	**D**	**G**	**F**	**H**
ACTIM	32.33	23.08	22.00	21.21	17.33	12.17	2.08	1.04
Duration	10.33	1.08	9.83	20.17	5.17	12.17	2.08	1.04
Resource Required	2	1	1	2	1	1	2	1
T Early	0	0	10.33	1.08	1.08	20.16	10.33	30.5
T Start	0	0	10.33	10.33	1.08	20.16	30.5	32.33
T Finish	10.33	1.08	20.16	30.5	6.25	32.33	32.58	33.37

Iteration #	**1**	**2**	**3**	**4**	**5**	**6**	**7**
T Now	0	1.08	6.25	10.33	20.16	30.5	32.33
Resource Available	~~3~~ ~~1~~ 0	~~1~~ 0	1	~~3~~ ~~2~~ 0	~~1~~ 0	~~2~~ 0	~~1~~ 0
Activities Allowed	~~A~~ ~~B~~	C ~~D~~	C	~~E~~ ~~C~~ F	F ~~G~~	~~F~~ H	~~H~~

Thus, the Total Duration for the completion of all the activities if only 3 Units of resources are available is 33.37 days

Glesson's Algorithm (same as Brook's Algorithm except that here ACTRES is used instead of ACTIM)

Activity	C	A	G	E	D	F	B	H
ACTRES	40.33	20.67	12.17	9.83	5.17	4.17	1.08	1.04
Duration	20.17	10.33	12.17	9.83	5.17	2.08	1.08	1.04
Resource Required	2	2	1	1	1	2	1	1
T Early	1.08	0	20.16	10.33	1.08	10.33	0	30.5
T Start	10.33	0	20.16	10.33	1.08	30.5	0	32.33
T Finish	30.5	10.33	32.33	20.16	6.25	32.58	1.08	33.37

Iteration #	1	2	3	4	5	6	7
T Now	0	1.08	6.25	10.33	20.16	30.5	32.33
Resource Available	~~3~~ ~~1~~ 0	~~1~~ 0	1	~~3~~ ~~1~~ 0	~~1~~ 0	~~2~~ 0	~~1~~ 0
Activities Allowed	~~A~~ ~~B~~	C ~~D~~	C	~~C~~ ~~E~~ F	F ~~G~~	~~F~~ H	~~H~~

Thus, the Total Duration for the completion of all the activities if only 3 Units of resources are available is 33.37 days

Sequencing

Processing Time, t | Due Date, d

Lateness (+ve or –ve), L | Tardiness (measure of Positive Lateness), T = Max(0,L)

Flow Time, F_i = Span between, task i Available for Processing & time at which Job i is completed

Completion Time, C_i = Span between beginning of 1st Job and when Job, i is Finished

If all Jobs are available at t=0, then $C_i = F_i$

Makespan = Span of Time when we start working on the 1st Job on the 1st Machine till we finish working on the Last Job on the Last Machine

Makespan for n tasks in Sequence s, $M_s = \sum_{i=1}^{n} t_i$

Mean Flow Time is Sequence s, $\overline{F_s} = \frac{1}{n}\sum_{i=1}^{n} F_{i,s}$

$L_{i,s} = C_{i,s} - d_i \mid T_{i,s} = Max\{0, L_{i,s}\} = Max\{0, C_{i,s} - d_i\}$

Mean Lateness in Sequence s, $\overline{L_s} = \frac{1}{n}\sum_{i=1}^{n} L_{i,s}$ | Mean Tardiness in Sequence s, $\overline{T_s} = \frac{1}{n}\sum_{i=1}^{n} T_{i,s}$

No. of Tardy Jobs, $N_t = \sum_{i=1}^{n} \delta_i$, where $\delta_i = 1\ if\ T_i > 0, \delta_i = 0\ otherwise$

$T_{Max} = \max\{0, L_{Max}\} \mid L_{Max} = \max\{L_{i,s}\}\ \forall i\ in\ n$

Sequencing n Jobs in One Machine

Hodgson's Algorithm (Minimize the number of Tardy Jobs)

Example

Task	1	2	3	4	5	6	7	8
t_i	5	8	6	3	10	14	7	3
d_i	15	10	15	25	20	40	45	50

Arrange the tasks in the order of Earliest Due Date rule

Task	2	1	3	5	4	6	7	8
t_i	8	5	6	10	3	14	7	3
C_i	8	13	19	29	32	46	53	56
d_i	10	15	15	20	25	40	45	50
L_i	-2	-2	4	9	7	6	8	6

Set aside Task 2 (since it is the 1st task with positive Lateness from the Left)

Task	1	3	5	4	6	7	8
t_i	5	6	10	3	14	7	3
C_i	5	11	21	24	38	45	48
d_i	15	15	20	25	40	45	50
L_i	-10	-14	1	-1	-2	0	-2

Set aside Task 5 (since it is the 1st task with positive Lateness from the Left)

Task	1	3	4	6	7	8	2	5
t_i	5	6	3	14	7	3	8	10
C_i	5	11	14	28	35	38	46	56
d_i	15	15	25	40	45	50	10	20
L_i	-10	-4	-11	-12	-10	-12	36	36

Only 2 Tardy Jobs

Sequencing n Jobs in Two Machine

Johnson's Algorithm

- Create a list of processing times of all jobs on machine 1 (*M*1) and machine 2 (*M*2).
- Identify the shortest processing time in this list. Break ties arbitrarily.
- If the shortest processing time is on *M*1, then assign the corresponding job to the next available position starting at the beginning of the sequence. Go to step 4. If it is on *M*2, then assign the corresponding job to the next available position starting from the end of the sequence. Go to step 4. .
- Remove the assigned job from the list. Repeat steps 2 and 3 until all jobs are assigned.

Sequencing n Jobs in Three Machine

Convert this into a Two Machine Problem

$Machine\ 1' = Machine\ 1 + Machine\ 2$

$Machine\ 2' = Machine\ 2 + Machine\ 3$

Condition for Optimality

The solution to the three machine problem will be optimal using the above method if

Either $Min\ T_{i_1} \geq Max\ t_{i_2}$ or $Min\ T_{i_3} \geq Max\ t_{i_2}$ is satisfied

If for some reason, the above conditions of optimality are not met, the procedure does not guarantee an optimal solution. It is however, still a very good Heuristic Solution.

Supply Chain Management

- Supply Chain design decisions involve significant investments in the number and size of plants to be built, number of trucks, number of warehouses to acquire and whether to buy or 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 the manner that will maximize profits.
- 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

Discount Factor $= \frac{1}{(1+K)}$ | Net Present Value (NPV) $= C_0 + \sum_{t=1}^{T}\left(\frac{1}{1+K}\right)^t C_t$

Higher the NPV, greater the financial return

Question

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 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?

For leasing on Spot Market Rate

Expected Profit $= 100{,}000 * \$1.22 - 100{,}000 * \$1.2 = \$2{,}000$

NPV(No Lease) $= C_0 + \frac{C_1}{1+K} + \frac{C_2}{(1+K)^2} = \$2000 + \frac{\$2000}{1+0.1} + \frac{\$2000}{(1+0.1)^2} = \$5{,}471$

For leasing on Spot Market Rate

Expected Profit $= 100{,}000 * \$1.22 - 100{,}000 * \$1 = \$22{,}000$

NPV(3 year Lease) $= C_0 + \frac{C_1}{1+K} + \frac{C_2}{(1+K)^2} = \$22000 + \frac{\$22000}{1+0.1} + \frac{\$22000}{(1+0.1)^2} = \$60{,}182$

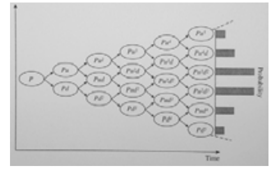
Thus Signing a lease gives \$54,711 higher NPV. This may not be the case if there is Uncertainty in Demand and Cost.

Presence 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.

- 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-*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*2*d*, *Pud*2, *Pd*3
  - Period 4: *Pu*4, *Pu*3*d*, *Pu*2*d*2, *Pud*3, *Pd*4



- 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*+2*u*, *P*+*u*-*d*, *P*-2*d*
  - Period 3: *P*+3*u*, *P*+2*u*-*d*, *P*+*u*-2*d*, *P*-3*d*
  - Period 4: *P*+4*u*, *P*+3*u*-*d*, *P*+2*u*-2*d*, *P*+*u*-3*d*, *P*-4*d*

Question

Demand = 100,000Units/year

Space required = 1,000 Sqft/1,000Units Discount Rate, k=0.10

Current Lease Rate(3 Years) = \$1.00

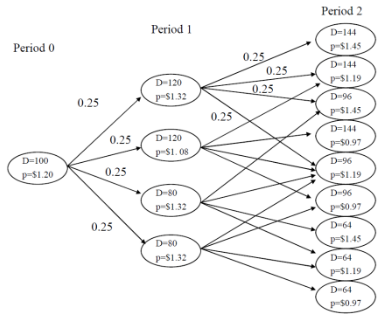
Spot Market Rate = \$1.20

Revenue per Unit in demand = \$1.22

Multiplicative Binomial,

Demand, may go up by 20% with p=0.5 & down by 20% with 1-p = 0.5 from one year to the next

Spot Market Rate, may go up by 10% with p=0.5 & down by 10% with p=0.5 from one year to the next.



- Start with Period 2 and calculate Profit for each Node
- Using the Calculated Profit of from all the Nodes in Period 2, compute the Present Value of Expected Profit of Period 2 in Period 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(calculate that using NPV)
- Using the Calculated Profit of from all the Nodes in Period 1, compute the Present Value of Expected Profit of Period 1 in Period0.
- The Total Expected profit is the sum of the profit in Period 0 and the present value of the expected profit in period 1(calculate that using NPV)

Node	Profit
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

Thus the NPV of Spot Market Rate,

NPV (D=100, p = 1.20, Period 0) = (100,000*1.22)-(100,000*1.20) + Present value of Expected Profit at Period 0(from period 1)

NPV = \$5,471

Node	Profit
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

Doing the Same by Signing the Lease, our Expected demand varies but cost of lease is constant, so it is only a single Uncertainty that we consider. That will give a NPV = \$38,364

Which is higher than not signing the lease, but it is lower than the NPV when Uncertainty wasn't considered.

Thus Signing a Lease is better for higher expected profit.