Supply Chain Analytics
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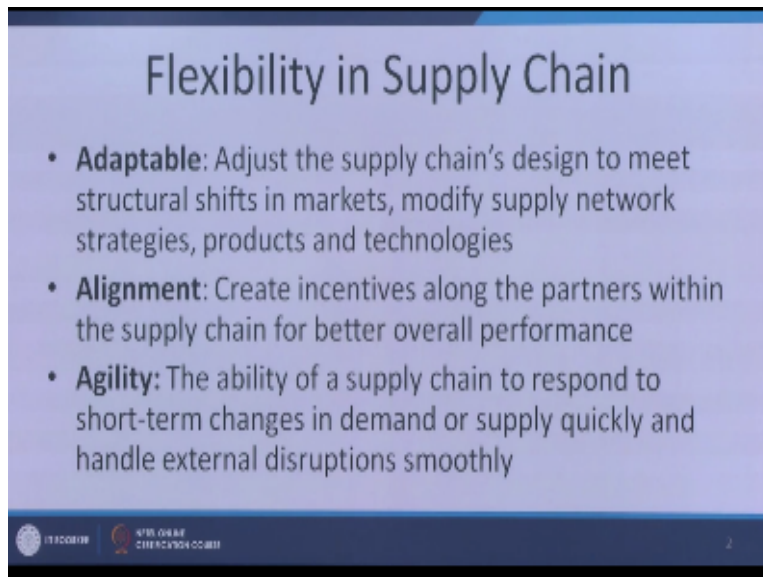**Indian Institute of Technology-Roorkee**

Lecture-39
Modelling Flexibility in Supply Chain

Welcome back till last few sessions we discussed about the uncertainty in the supply chain and we try to understand the modelling related to uncertainty in the supply chain with the help of a question where we want to discuss that where should we develop our facilities and we took an example where we have a particular demand and there is a particular price of the commodity and over the period of time demand can also fluctuate and price can also fluctuate.

And we had two options either we can go for a lease contract or we can go for the spot market, with the help of decision tree analysis we developed a decision tree and we saw that how can we evaluate alternatives to get the best option, now this is all about business analytics that we want to predict about the future as accurate as possible and obviously given a variety of alternatives I would like to select one alternative which maximizes my expected profit.

Now flexibility is one such area which we need to incorporate in our supply chain for handling these uncertainties because earlier there was a time we used to have almost lot of certainty with respect to various underlying factors of the supply chain. But as we all see we are seeing so many things which are uncertain and all of a sudden these things makeup and to handle those things flexibility is required in the supply chain.

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Flexibility in Supply Chain

- **Adaptable**: Adjust the supply chain's design to meet structural shifts in markets, modify supply network strategies, products and technologies
- **Alignment**: Create incentives along the partners within the supply chain for better overall performance
- **Agility**: The ability of a supply chain to respond to short-term changes in demand or supply quickly and handle external disruptions smoothly

In our area class also we had a little bit of discussion about the flexibility in the supply chain that we need to have adaptable supply chains, we need to have a line supply chain and we also need to have agility in our supply chain, where we're supply chain can respond quickly in short time to the changes of demand and supply. Our supply chain should be creating such type of incentives along the partners within the supply chain for better overall performance.

If in a supply chain environment when we have a vendor, manufacturer, wholesaler, retailer, these different entities are there but normally we all know that if one YM is there in a supply chain so normally YM designs this supply chain such a way that he takes the maximum amount of profit, so now when we are talking of alignment the supply chain should be developed in such a way that the equal share or the professional share of all the partners of the supply chain can be taken care of.

Then adaptable where my supply chain can adapt to the design to meet the structural shift in market, it can modify supply network study this product, technologies etc. We had the case of Dell where earlier Dell was supplying only through online order and that was one of the USB of Dell, but over a period of time when Dell realise that now it is no longer profitable to supply through that online mode.

So then also started brick and mortar system the retail system of distribution of the products, so you need to be adaptable as per the changing requirements otherwise you will be out of the market. So these are the three important elements of the flexibility.

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ABC 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

Now we will continue with our example of this ABC logistics which we discussed in detail in our last session and from this point we will like to see that how the flexible options are better than 2 dedicated options which we have discussed, 1 dedicated option if you remember we discussed where we had all warehousing space from the spot market and then other dedicated option was to sign a 3 year lease for a fixed amount of time and he is worthy to dedicated options.

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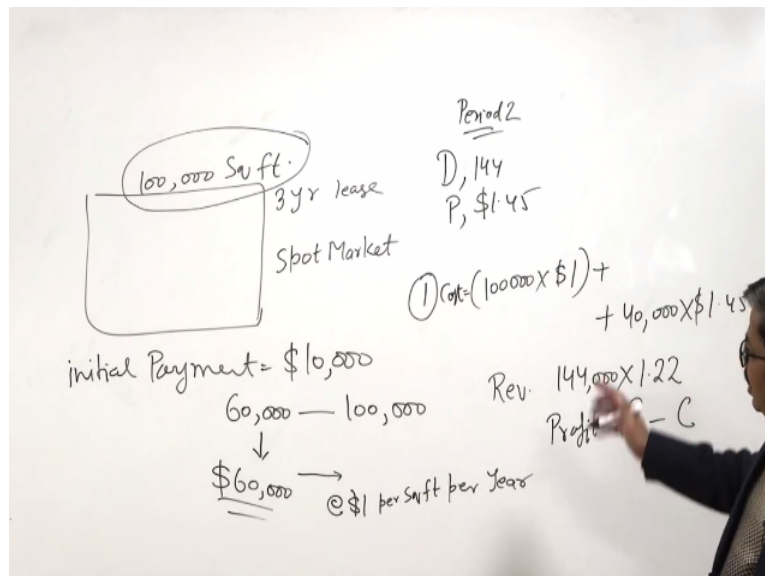
Now we want to incorporate flexibility into this discussion and flexibility that I want to use I have this 100000 square feet area which I can go for a lease of 3 years or I do not take this area I take my spot market option, so these worries first two cases. So the third option is to sign a flexible lease deal where we pay some minimum charge of front which makes us used to be for this 100000 square feet.

But there will be a kind of variable arrangement that if I don't want the complete space I pay only for a limited space and then remaining space can also be paid on some kind of additional rental. So here in earlier cases if you remember if my demand is not 10000 units the in that case I was having some space which is unused and still I was paying the rent for that if I was having the lease agreement. A spot market I always need to buy space on a higher price from the market.

So there were limitations of lease agreement as well as of the spot market. So in this case in this flexible case I want to take the benefit of spot market as well as flexibility or as well as the low cost of the lease system. So now we will see that how are we going to model such type of situation.

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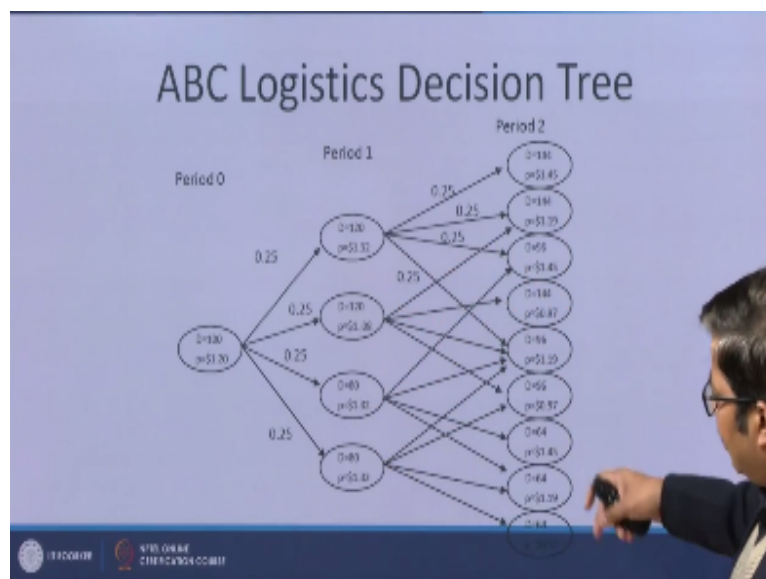
We already discussed in our earlier session that how did we develop this decision tree, so same just for a quick re-capsulation this is the initial demand of the product that is 100 and these are the rate of my spot market that is 1.20 square feet per for the spot market and we have discussed that there are possibilities of increasing the demand or decreasing the demand by 20%.

So in the next period demand can increase by 20% then it becomes 120 and demand can decrease by 20% then it becomes 80, 80 similarly price can increase by 10% for the spot market or price can decrease also by 10% when it increases it become 1.32, when it decrease

it becomes 1.08 so therefore these 4 states are possible in period. Now from these 4 states in period 1 of these states will further give rice to 4 different states in period 2.

There will be many common states also therefore we do not have 4 x 4 416 distinct states in period 2, like you see for this second state here where the demand is 144 and price is 1.19, so you get this arrow here and this arrow also here. So this state is common for two possible outcomes from state one and state two of period one.

So it is called see possible like in this case we demand is 96 and price is 1.19 dollars, you ar seeing 4 arrows coming to this, this state is 1 states which is possible from all 4 states of period one. So therefore we do not have 16 distinct states in period 2, we have only some 9 different states in period 2. Now after and same logic applies to this period also that demand 120 can increase or decrease by 20%.

So if it increases by 20% it becomes 144 if it decreases by 20% it becomes 96 and 96. The price 1.32 can increase by 10% can decrease by 10%, so when it increases by 10% 1.32 becomes 1.45 price because 1.45 in period 2 and when price decreases by 10% 1.32 it becomes 1.19, so these are the two states where price decreases and these are the 2 states where demand increases.

Now the possibility the probability which we are taking that is 50% for increase or decrease of the demand similarly 50% is the probability of increase or decrease of the price of the spot market so and these things are independent the increase of demand or decrease of demand, increase of price or decrease of demands, so both these are independent.

So therefore the transition probabilities from this state to this state or from this is state to any of these 4 states will be the multiplication of two different things, 0.5 is the probability of increase of the demand, 0.5 is the probability of increase of the price, so 0./5 x 0.5 becomes. 25, so therefore these are the probabilities 0.25 0.25 0.25 and similarly these are probabilities 0.25 0.25 0.25 and 0.25, so this discussion tree and this discuss we already had in our previous session.

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ABC 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

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

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

$$= -\$12,000$$

Now in the previous we evaluated the two possibilities one possibility when we have the lease system and what is that and one possibility when we are going to have the spot market, so these 2 things we have already evaluated and we saw that lease system and this is the possibility of the profit expected profit when we are going to have the lease for 3 years that is 38364 and the possibility of profit from the spot market the expected profit from the spot market is 5,471 dollars.

If I compare between spot market and lease I will obviously go for the lease because this is giving me much higher profit. Now I will like to evaluate the third type of alternative which is the subject matter of discretion today that is the flexibility in the supply chain decision. Now I want to incorporate this flexibility in this discussion and in the flexibility you see we will use the same decision tree which I just explained you in detail.

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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 ABC 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. ABC 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 $46545
- 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 a Table, where the flexible option has an expected present value $8,361 greater than the inflexible lease option (including the upfront $10,000 payment)

Now the issue is this that the manager at ABC logistics has been offered a contract where foreign upfront payment of 10,000 dollar, I paid 10,000 dollar today that is that will make me you can say a kind of tentatively I can hold this space with 10,000 dollars, so this is the initial payment I am going to make that is 10,000 dollar, the initial payment and now the company has the flexibility of using between 60000 square feet to 100000 square feet of warehouse space at the rate of 1 dollar per square feet per year.

So I can use from 60000 to 100,000 I can use, but you can understand from this language that I need to pay dollar 60000 for the first 60000, I need to pay first for this is 60,000 square feet dollar 60000 that I need to pay whether I am using it or not, so that way you can say this component in this flexible case is this 60000 square feet. The remaining if I use more than that if my requirement is 70000, 80000, 90000.

So I need to pay for this 100000, so the remaining space which I use for that additional at the rate of dollar 1 per square feet per year I will pay, so this is that 60000 for that purpose I am paying 60,000 dollars and the remaining up to 40000 square feet on demand as per my demand I will pay for dollar 1 per square feet per year. Now doing the calculation as we did in the case of any of the earlier methods.

So we go back to this decision tree and will like to see that how this method is applicable. When my demand is let say I take two scenarios to make you understand that how you calculation will proceed. So we will start from period 2 and in period 2 let us take two, three

different scenarios one scenario where the demand is 144 at spot market prices 1.45 demand, when demand is 144 units, price is 1.45 and this I am talking in period 2.

So when this is the data, so out of this 144000 units of demand I will like to fulfill my 100,000 demand from the lease agreement, so for that purpose my cost is 100,000 x that is the at the rate of 1 dollar per square feet will be available to meet + for having this kind of arrangement I have already paid upfront payment of 10,000 dollars, so that also will come and at the same time the remaining 44000 for that purpose I will require the spot market.

So for 40000 you need to add spot market trade that is 1.45, so this is going to be the cost that this is the cost because of the lease agreement and this is the cost because of the spot market, so this is one scenario of the cost and obviously because you are selling 144000 units, so when you will be 144000 and you can remember the data that we are selling at the rate of 1.22, so that is the rate at which we are selling.

So revenue - this is the cost component, so revenue - cost will give you the profit for period number 2, this is going to give you a profit for period number 2, now it is up to us that we can eliminate this 10000 right now in this calculations and once we come with the final calculation in that also we can add that whatever profit we are getting we will subtract 10000 in that, so that will also be possible.

So instead of adding 10000 here we will add 10000 in the last of our cost components and from the total profit we will subtract 10000 for getting this initial payment of the lease agreement, so this is your now profit will be revenue - cost that is the profit for period number 2. When I come to period number 1 with this data I will calculate the present value of the future cash by dividing be this value of profit by your factor of discount that we remember if the 10%.

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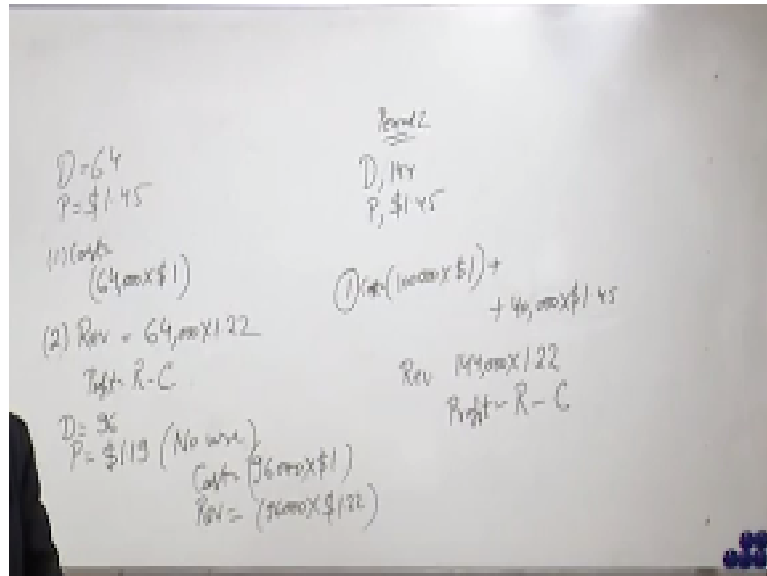
Not come to a different situation where d =64 and the spot market price is 1.45, now the another situation is d =64 and spot market prices 1.45, so let us see how our calculations get change when the price is 1.45 and demand is 64 and spot market price is 1.45, since again we have this initial arrangement and in the case the cost component is 60000 for that I am already paying at the rate of 1 per square feet and I am also taking 4000 additional space.

So for 64000 the total cost will be at the rate of 1 and I will not go to the spot market because I have total availability of space 10000 square feet and requirement is 64000 square feet, so this price of 1.45 is not applicable right now in this calculation, this price has no meaning I have zero spot market cost to this spot market cost in this case of 64, 1.45 is no reason it is not applicable to macro environment.

So I will only incur this cost and then the revenue is 64000 x 1.22 and then I also calculate the profit that is R – C. Similarly if I go to this calculation d = 96 and spot market price is 1.19, and this calculation also d= 96000 and spot market price is 1.19. Now this 96 is also less than 10000 and therefore again there is no use of this spot market price, because my warehouse for which I am making a flexible arrangement can accommodate up to 100,000 units.

Because the size is 100000, so for 96000, 60000 at the rate of 1 and additional 36000 again at the rate of 1, so for 96000 my cost will be 96000 square feet I will take at the rate of 1 dollar, so that is my total cost and revenue will be simply 96000 x 1.22. So that is against I can

calculate the profit. So here by using this flexible system I will not incur any additional cost because of unused capacity.

Now you see in these two cases 64 and 96 where I am not able to use entire 100000 square feet of the warehouse, if I would have gone for completely lease arrangement, so what would have happened that I will have some unused capacity of 4000, I will have a news capacity of 36000 and I am paying rent for that, so I am saving that amount of rent and therefore this is much more profitable.

And then with this calculation you I request all my students that please make this calculation complete and when you make this calculation complete you will see that the total amount of profit is coming to be 46,545 dollars, this is the total amount of profit which will come that is 46545 and in this calculation of profit I have already subtracted the 10,000 dollars which we had made as upfront payment.

So that amount we have already subtracted, so now if you compare be 46000 we are getting here, the lease agreement was giving us 38364 and spot market was giving us 5471, so obviously out of this 3 alternatives I will like to select this flexible arrangement, because this is giving me maximum expected profit. Now because here we have only two conditions and price is either increasing or decreasing by 50%.

And demand is also increasing or decreasing by 50%, so you have only 2, 2 situation but as the amount of uncertainty increases as the amount of uncertainty will be increasing be flexible options give you more profitable or more value in the answers, so when your uncertainties are higher it is always advisable to go for more flexible options. Because in that case the dedicated options may go unused if you don't have enough demand, enough supply.

So in that case he dedicated options will give you higher cost of higher fixed cost of your plant and machinery etc. So therefore be flexible option is very very useful and you can see that in this particular example where we had only two options that how incorporating a very little bit of flexibility, now you can do one more thing and you can take this as part of your assignment also or as a practice question that for first 60000 with prices at 1 dollar per square feet.

So for 60000 you are paying 60,000 dollars, now for the remaining space up to 40000 the price is increased by 10 cents, it is 1.1 dollar for any additional space after 60000 and I request to do a revision of the entire calculation and in that again you will see that what type of changes are there. Because this is a very simple case we took to understand this phenomena.

But you can see that how be increased cost of the because alternative for different, so you can have the additional space at a slightly higher rate than this dollar 1 per square feet, so you can try that option also. Now going further into the discussion we will see that you may like to establish these two types of facilities.

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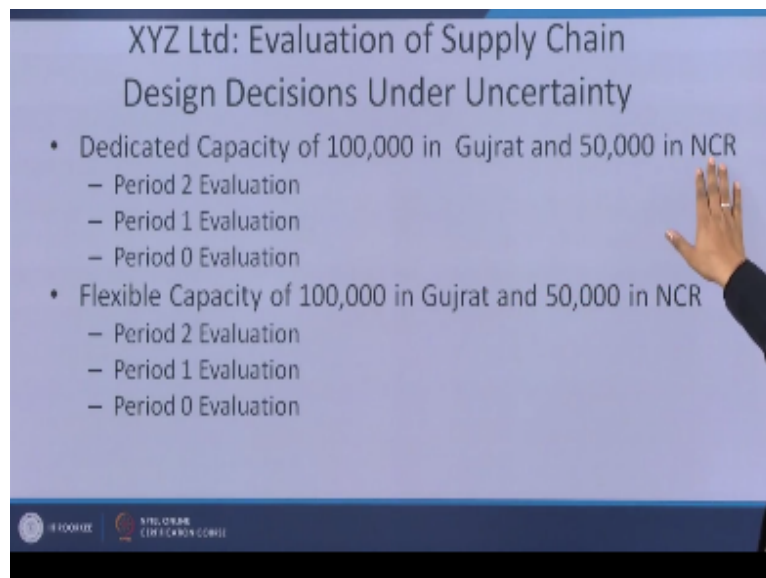
So it is a different type of situation where you can have dedicated capacity of 100000 units in Gujarat and similar dedicated capacity of 50000 in national capital region, then you have another issue that you can have a flexible capacity of 100,000 units in Gujarat and 50000 units in NCR and again we are going to evaluated for 3 period from 0, 1 and 2.

So let us see that what is the difference between dedicated and flexible capacity. In these two cases when we want to make any product and you can take the I am taking Gujarat and NCR it will be more appropriate if you take two different countries and in that case you can incorporate the issues related to exchange rates also.

So you can try that you replace Gujarat by India and taking place of NCR you take country like Vietnam so it can be India and Vietnam also, so that will make this discussion more

interesting and not only the demand and price the other charges rate fluctuations will also come into picture.

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So the data available to us is like that for investment for the dedicated plant and for the flexible plant, the size of the plant is 100,000 and 500000 respectively the fixed cost for the dedicated plant is one million per year at Gujarat and NCR because the land prices are very high it is 4 million per year. So we are making tyre, so the variable cost is 15 dollar here and it is 11 here.

And similarly for the flexible plant it is 1.1 million years and 4.4 million per year and variable cost is same it is as for the fix a dedicated plan that is 15 dollar and 11 dollars respectively. Now the expected demand related to which Gujarat plant can fulfill is 100,000 initially and the demand from the NCR plan to meet is 50000 and there is a probability that demand can increase or decrease by 20% over a period of time per period with a probability.

And let us say since we are cancelling only one probability of 20% of increasing or decreasing the demand, so 50% of 50% down let us go with this simple assumption.

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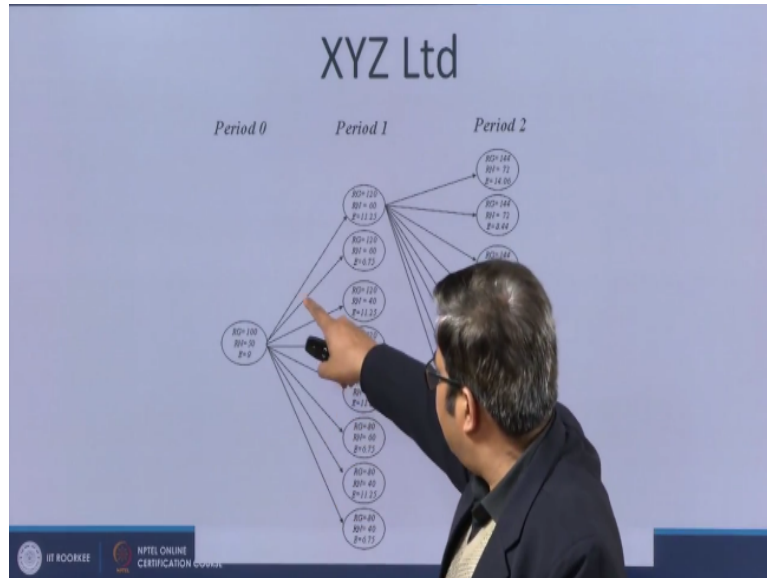
Now when we consider this and these are the two plants of 100, 50 and to take this example on the international level I have given a value of exchange rate also, so this stand for the exchange rate and there are these possible states which way emerge from period zero to one and one to two and I request my students that please try to write the various transitive probabilities on these arrows.

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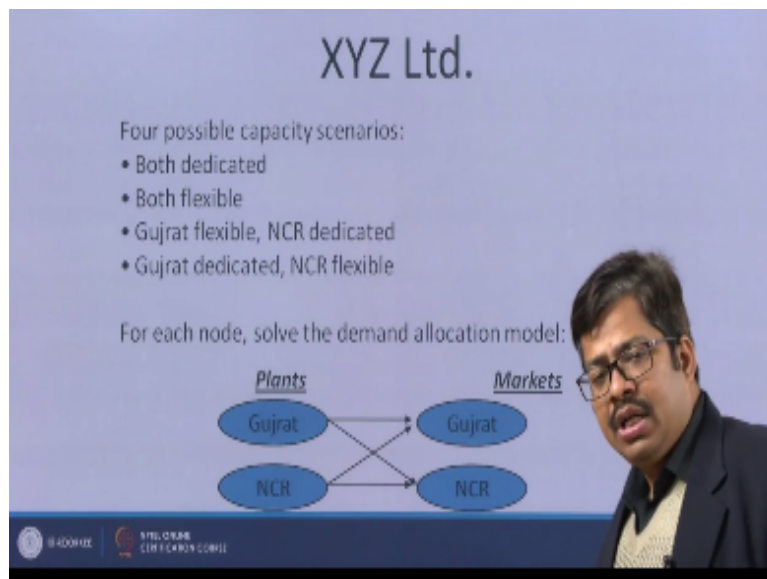
So you do not see this graph I am not putting that slide for long and you can develop this payable on your own this decision tree on your own and once you have this decision tree available with you then you can have these possible scenarios that at both the places you have dedicated plant at both the places you have a flexible plant, you have a flexible plant and Gujarat and dedicated plant at NCR.

And this becomes a question for you that you can see that how with different plants you can serve with different markets like this Gujarat plant will serve the Gujarat related area and answer related area also be NCR plant conserve the Gujarat area also and NCR related area also so you can have this types of scenarios possible and it will be very interesting if you develop the entire decision tree.

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Facility Decision at XYZ Ltd

Plant Configuration		NPV
Gujrat	NCR	
Dedicated	Dedicated	$1,629,319
Flexible	Dedicated	$1,514,322
Dedicated	Flexible	$1,722,447
Flexible	Flexible	$1,529,758

And I expect that you develop this decision tree on a spreadsheet and then the calculation will be much easier and finally you can have this type of net present value I am giving you the final slide where if you have dedicated plant at both locations at Gujarat and NCR, the net present value is this figure then flexible plant at Gujarat and dedicated plant at NCR, so out of all these net present value calculation you find that the highest net present value is available for the combination of dedicated plant at Gujarat and the flexible plant at NCR.

So this way you could find that which is the most profitable configuration of our plants and this is what we mean by incorporating flexibility in supply chain. So whenever uncertainty is there and when uncertainty is higher we need to include flexibility and as you go uncertainty is highest as in earlier case we considered only two parameters, one parameter was the demand and another parameter was the price of the spot market.

In this example we took three aspects we consider 2 markets their demands and second was the exchange rate fluctuations also if it is a global kind of supply chain, so here we had three different type of parameters and therefore more uncertainty is there. So as you increase the number of underlying parameters in the decision tree you will have more states, more states

means more uncertainty and therefore the flexibility in the supply chain will give you the better answers.

So with this simple tour of decision tree and developing the payoff table and on the basis of that you calculate the net present value and finally we can see that out of various alternatives which alternative is the most profitable one, means which alternative is giving you the highest net present value of the future cash flows, so accordingly you can take the decision. Thank you very much and with this we complete the discussion of uncertainty in the supply chain design.