Infrastructure Planning and Management
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Module Flexibilities in Projects Part 1

So today what we are going to try to do is actually test that assumption quantitatively and show a little bit about ways in which we can model flexibility on projects to actually determine what kinds of flexibility yields what kinds of value. To do this we are going to use some teaching material which I have not created but it was created at MIT by you know professor called Richard de Neufville who works a lot on flexibility in infrastructure, he is part of the engineering systems group I believe in MIT or was I think he is more or less retired now and when I met Richard a few years ago and I said look you have wonderful material he said please feel free to steal it from me ok, so true to his wishes we are actually taking his material it is all available publicly anyway.

So and we are going to use that because it very nicely done case ok. So let us just first look at the case itself, so let me sort of explain a few things to you the issue at hand here is that you are going to build a plant that manufactures something right we do not know what you can imagine you can use your imagination to figure out whatever that is something is based on what you want it to be.

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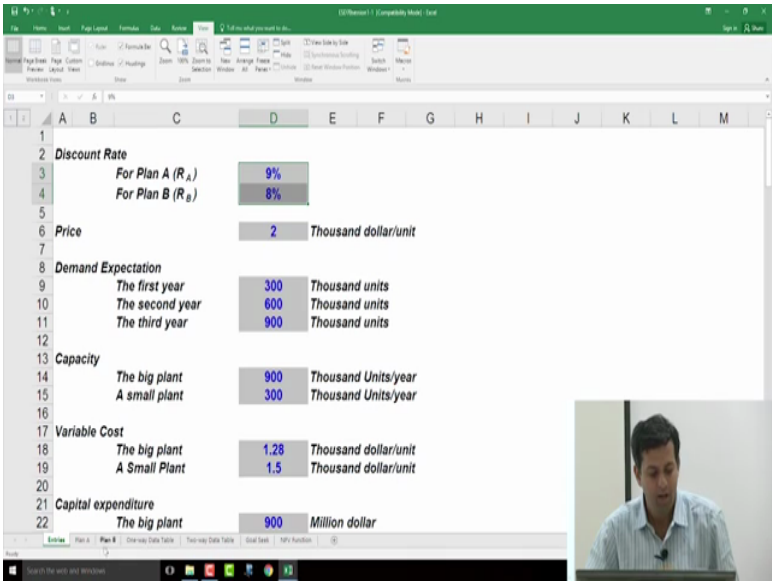

But there are two options, so if you look here right there is an option of building a big plant ok, this big plant will produce 900 thousand units a year all right and the price of each unit as you can see is about 2 thousand dollars a unit ok, so the big plant produces 900 dollars a 900

thousand units a year. On the other hand there is a small plant, the small plant can only produce 300 thousand units a year but you have the ability to build multiple small plants if you like all right.

So essentially you have two strategies one is you build a large plant right the second is you build multiple small plants ok, there is also some expectation on demand right and demand is going to increase as time goes on all right. So this is fundamentally the situation when you start looking at costs the cost of building the big plant is 900 million dollars, the cost of building the small plant is 300 million dollars right.

So it is proportional 300 million dollar plant manufactures 300 thousand units, 900 million dollar plant manufactures 900 thousand units right, the change is on the variable cost right the fixed costs are roughly proportional with regards to variable costs right the big plants variable costs are thousand two hundred and eighteen dollars per unit all right whereas the small plant actually costs a bit more thousand five hundred dollars a unit all right possibly because there are economies of scale at play right.

So you have a big plant with you know the you have much more material going in you are probably able to amortized that material across a number of processes, you have what we call economies of scale as you get larger volume production and therefore maybe the costs come down right. So you have two options big plant, small plant right big plant produces more, small plant does not produce that much, big plant actually costs less to operate, small plant costs a little bit more to operate and you also have this demand variable where demand is slowly going to increase ok, over three years.

Now let us say you have a three year horizon intuitively would you rather pick a big plant or would you rather pick the small plants? Ok, intuitively what do you guys feel like doing three years let us just take a three horizon for now, it is just looking at three year horizon would you guys rather build a big plant or would you guys rather build a build small plants? Small plants ok, intuitively and what would you, you know how would you go about building your small plants? Right would you build all three of your small plants in the first year? Right what do you think would be a good strategy for you?

Student is answering: With increase a demand means that.

Professor: So with increase in demand you will start increasing the plant, so given that the demand is 300, 600. 900 what is likely to be your small plant strategy?

Student is answering: 1st year, 2nd year, 3rd year, one, one plant.

Professor: So you will do one, one plant, first year you will build one plant, second year you will build the second plant, third year you will build the third plant right, that way you do not have to spend 900 million dollars upfront, you can spend 300 this year, 300 next year, 300 the year after exactly right, so that is intuitive. Now let us look at let us just do a you know a calculation to figure out what which one actually is a better option given these numbers right, I have also given discount rates option A has a discount rate of 9 percent, option B has a discount rate of 8 percent we will play with these a little bit right but option B seems to be a bit of a safer option, so slightly lesser discount rate all of them, alright.

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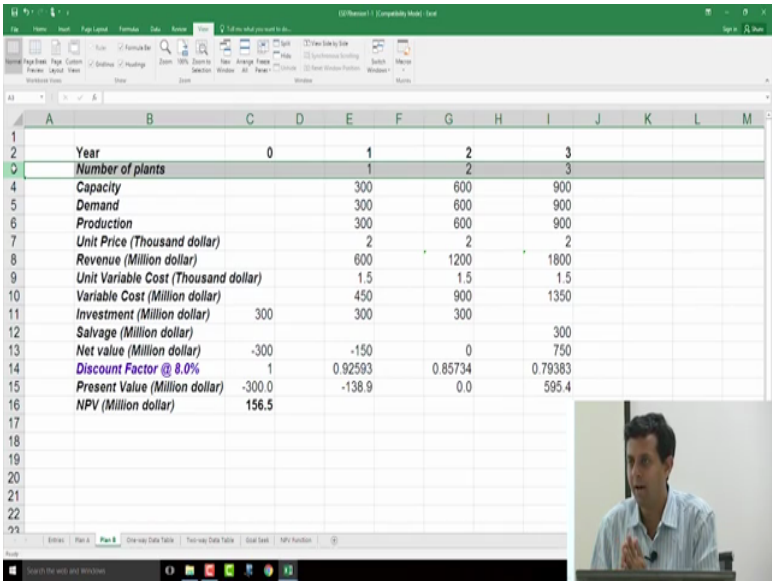

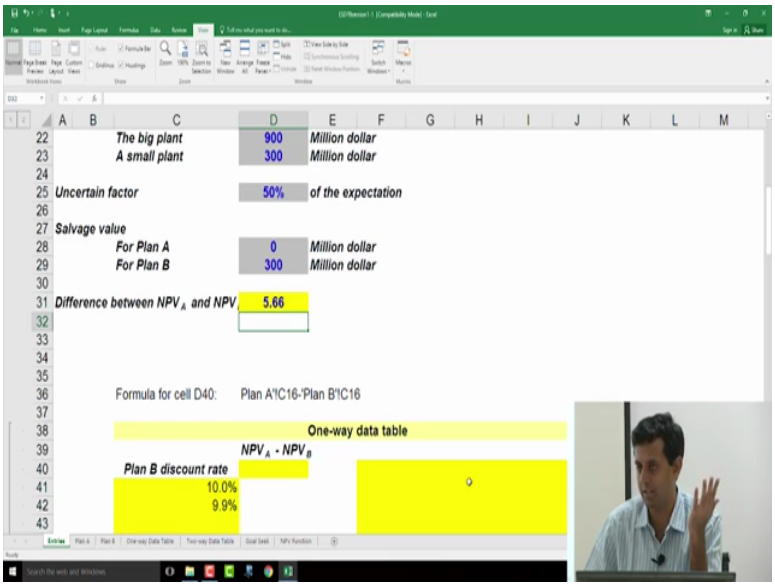

So let us go to the plan A data sheet, so one of the things we want to do is get to each of these has to now be zoomed ok, one of the things we want to do is also figure out ways in which we are you know we can use Excel in a neat fashion and one of the ways in which you use Excel to build these models is you actually have an assumption sheet, where you put all your assumptions and then you draw from those assumptions as you do your calculations right.

There for what happens, so this sheet entry sheet has most of my assumptions right every time whether it is plan A or whether it is plan B every time I want to draw from an assumption all right I go to the entries sheet, the reason is if I need to change something right if demand changes right it is not 300, 600, 900 it is 4008, 400, 800, 1200 I just change it here once in this entry sheet and that will then be reflected on all my other spread sheets because I am referring to the main sheet right, so that is just good practice ok.

So using that let us sort of ok look at the large plant option and how we would model it all right, so we have your 0, year 1, year 2 and year 3 right what happens in year 0 you know essentially you know nothing much seems to happen in (zer) year 0, year 1 essentially we build 1 plant ok so I am going to go to this so you can start filling this as we go along, so the number of plants in year 1 is 1 ok that is clear, all right therefore what is the capacity of production in year 1?

Student is answering: 900.

Professor: 900, right the each the big plant can build 900 ok, so I am going to go to this slide when you say capacity I am going to say equal to if I can find the equal to there we are, the equal to go to the entry sheet and look and click on this cell D14 which is the capacity of the big plant right, now click enter so the capacity at the year 1 is I have one plant and therefore it is the capacity of that 1 plant right technically it should actually be yeah it should actually be this multiplied by the number of plants I have, each plant has 900 unit capacity and therefore I will in year one I have 900 units times one plant because I have one plant at the end of the year ok, what is the demand?

Student is answering: 300.

Professor: Demand is 300 where do I get this from again I say equal to I go to this sheet oop sorry and I just click on the demand in the first year, so the demand is 300 thousand units all right. So my demand is 300, my capacity of production is 900 how much do I actually produce?

Student is answering: 300.

Professor: 300 right, because 300 is the demand right, so I have a capacity to produce 900 but I do not produce that much right so here in this cell I say equal to and then I use this function called minimum right I say MIN open bracket and I just select both of these cells A4 colon A5 or if you just select both of these cells you close the bracket press enter right, essentially takes the minimum of a 2 of both right

So I am putting this in formulaically because tomorrow or you know whatever in half an hour if I want to change these demand estimates and production estimates all I need to do is change my assumptions the entry sheet and the rest will automatically change right, so the formula is how much am i producing is a function of the minimum of what is required and what capacity I have, tomorrow if you say produce 1200 units I will only produce 900 because that is my capacity ok.

What is the unit price that is already given so the unit price of all of this is where is the unit price is 2 thousand dollars a unit ok, so that is a given and therefore what is the revenue that I am making? What is the revenue that I am making in year 1, the revenue that I expect to make right.

Student is answering: (())(08:57).

Professor: Right, so essentially I say equal to the unit price or sorry the production multiplied by the unit price so unit price multiplied by the production right so I am producing 300 I am getting two for each and therefore I am going to get 600 thousand dollars all right, ok. So the unit variable cost which is row 9 that is easy as well because that is already there the unit variable cost for the big plant is 1 point 28 right and therefore the question is what is the total variable cost?

So I am going to get 600 thousand dollars right in terms of revenue what is my total variable cost? My total variable cost is the amount I am producing multiplied by the variable cost per unit right, so the variable cost (pla) per unit is 1 point 28 and I am producing 300 thousand units right, so this is my overall variable cost, my unit variable cost was 1 point 28 my overall variable cost is 384 because I am producing 300 all right, tomorrow if I chose to produce 400 or 450 then my overall variable cost will go up ok.

With regards to my investment so the way the spread sheet has already worked is by saying that I have a plant at in year 1 to produce I have already invested at t equals 0 right, so t equal 0 I invested the plant and therefore it is now producing something for me, so my investment at the point is 0 there is probably I can probably do this formulaically as well where essentially what I would do is I would say it is the cost of a plant, so in other words if I am going to make any investment now it is investment for the following year ok.

So the way I would do that is I would say this is equal to what is the cost of the plant right, it is 900 million dollars multiplied by and I will open brackets the amount of capacity I need next year minus the capacity that I already have this year right, so essentially I am saying look if I choose to expand then I have to invest for that expansion now, so if I wanted 2 plants next year right and I have 1 plant this year then 2 minus 1 I need 1 more plant and that will cost me another 900 but in the current scenario I have 1 plant this year I only have 1 plant next year, I do not I am not investing any right, so I am the answer is 0 but I am doing it for formulaically because tomorrow I can go ahead and change these assumptions right I can go ahead and change number of plants I can say this is 2 and the moment I say this is 2 those numbers change ok, all right.

Salvage it is a good question there was some salvage data here below salvage for plan A there is no salvage and plan B there was a salvage that makes plan A even better ok and then the question is what does what is there for the net value or revenue or whatever that I am coming and that I am getting this year right, so the net value or revenue I am getting this year is the sum of all the inflows, so the inflows are revenue and the inflows are also salvage of course I am getting no salvage but that is still an inflow ok and my outflows are my variable cost which is 384 and the investment which happens to be 0 but if I were to invest then that would be a next, phase right.

So E8 and E12 well are my inflows right revenue and salvage E10 and E11 are my outflows right variable cost at capital cost right, so we should all get 216 ok. Now this is happening in year one, so I have to start discounting it right. The it was a 9 percent discount rate, so how much should I discount all of my cash flows at the end of year 1?

Student is answering: (())(13:20).

Professor: What is the formula? Right, so should I just add up to 216 and 432 and 648 and 900 obviously I cannot right, because I have to discount them by how much do I discount 2 1 2 1 6 at a 9 percent interest rate what would be the discount factor?

Student is answering: 1 point 09.

Professor: 1 point 09 right, because it is one year out right the 432 is getting discounted 1 point 09 square the 648 is getting discounted 1 point 09 cube right. So this discount factor again I am just going to put it in a formula it is 1 divided by it is 1 by 1 plus r raise to n right, r is 9 percent and n is 1 so I am just going to put it formulaically 1 plus r let us find the r here 1 plus p and exponent which is the caret above the 6 the number 6 on your keyboard n, n which is the year here ok.

So essentially I have done 1 by 1 point 09 right, so 1 by 1 point 09 we can even check it here equals 1 by 1 point 09 is point 91473 right it is exactly the same thing, I have just done it to make us just done it formulaically all right. So therefore this 216 the present value of that 216 is how much?

Student is answering: (())(14:53).

Professor: So 216 multiplied by point 91 which is 1 by point 09, so I will let me just multiply these two right which is 198, so the present value so I am making 216 rupees next year but in today is terms that is 198 because I am applying a 9 percent discount factor, so in a 3 a horizon I am spending 900 rupees the first year I am making 216, 432 and 648 in three years but of course those future cash flows are getting discounted.

So actually the 900 remains 900 but 216 becomes 198, 430 becomes 363, 648 becomes 500 because I am discounting it. So my overall net present value right will be the sum of all of these discounted cash flows because I have already discounted them, so now I can add them right so I have already discounted them, so I get 162 point 1 ok, you all should get 162 point 1 this is there is no this is completely deterministic right everyone needs to get 162 point 1, so do you all have 162 point 1, shut this off sorry I think this is what is causing the interference yeah.

Student is questioning: Salvage value mixing calculated all the here?

Professor: No, the salvage value will be calculated yeah, so if you look at the salvage value it is really there yeah so it depends on whether you were going to get rid of the plant and in fact

if you look at the explanation it says the salvage value which only occurs in year 3, so the input is in fact I probably do not even have to do this formula you are right, I just think I should just put in a physical 0 there.

Student is questioning: So then only the final year (())(16:45)?

Professor: Yeah because only the final year I will get the salvage right, so even if there was a salvage right I should have just put in I mean it is just a 0 because I am not selling the plant here ok, 216 oh sorry 162 point 1 who is who does not get 162 point 1 ok, everyone gets 162 point 1 ok. Now let us go back to the entries sheet and do so if you go to plan B you will find that this has already been done for you right, so if we go to the plan B sheet it is already been done for us right.

So let us go back to the entry sheet and in row 31 it says difference between NPV A and NPV B right, let us just say find out what the difference is. So I am going to say equal to NPV A is select that cell - NPV B right, so in other words it is 5 point 66 right, so I am just subtracting we got 162 point 1 we had already calculated you know the people who prepared the spread sheet had already calculated Plan B and they had 256 point 5, so I am just subtracting the 2 right, so I get a net NPV difference of 5 point 66 right just plan A NPV - Plan B NPV just selecting this cell minus that cell, make sure you put the equal to in front who is not getting 5 point 66? It was good, what does this mean?

Student is answering: Plan A better than plan B.

Professor: So at the moment it looks like plan A is better than plan B right, I am getting a slightly higher net present value with regards to planning, so even though Plan B was modular you know and all of that and even though it had a salvage value and all of these kinds of things which was taken into account in that spread sheet, the fact of the matter is that plan A ends up working out much better yeah.

Student is questioning: Sir, in a plan B the salvage value will be mention a 300 into just of 1 (())(18:48).

Professor: Yeah I think yeah, so that the entries assumption the salvage value is not per plant it is per plan right, right so the plan B salvage is 300 so at the end of the third year when you sell all your plants you get 300 ok but if you look at Plan B you will find that so they have done this assumption right, so the first year there is 1 plant in the second year there is 2 plants

in the third year there is a third plant, so they have added plants incrementally, so they have not spent 900 upfront they have spent 300 but still they are not making a big profit maybe because the variable costs of plant B are higher right, so whatever at the moment plant A is better than plan A is better than plan B all right, ok.

So now the first thing we can do is do a little bit of so everyone is ok here? We are all of the same page right because the problem is we get left behind you will never catch up right so if you are not there we can take a moment we can pause everyone is ok? Done, ok so this is just the baseline, where are you guys stuck, all good ok.

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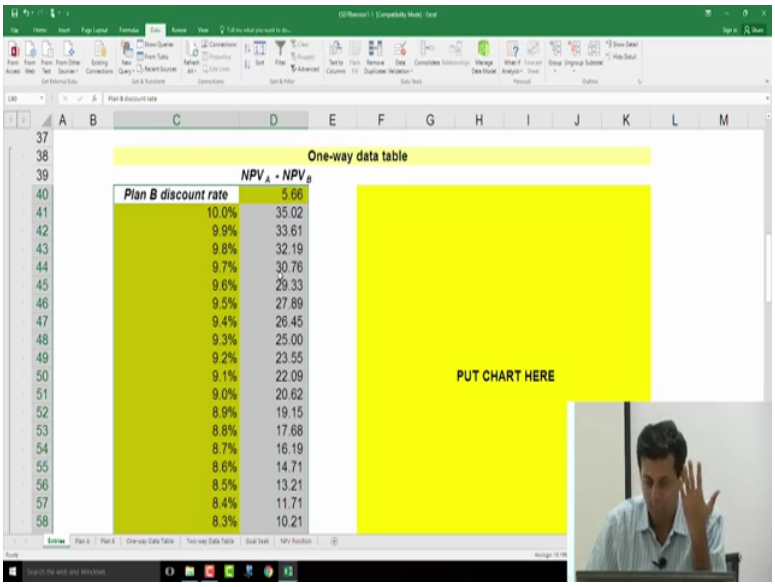

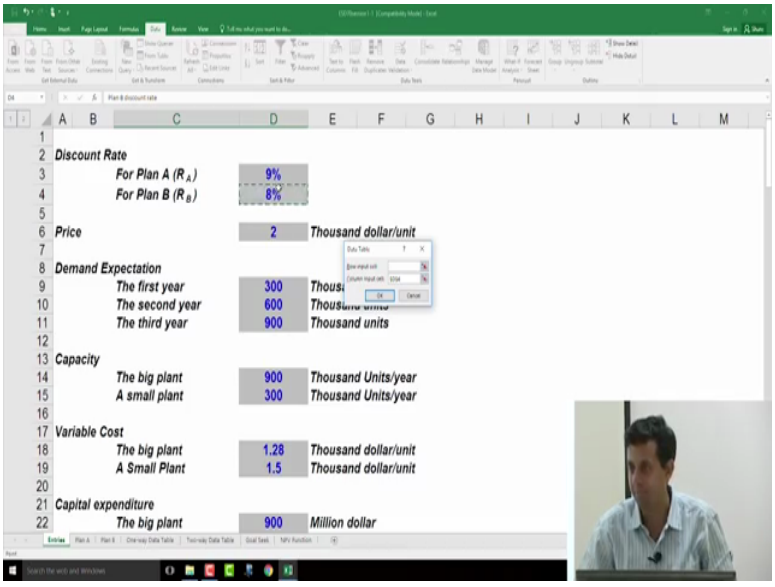

So now one of the things that people might we might sort of worry is ok how sensitive is all of this? What happens if the you know the variable cost was a little bit different right whether

it was a little bit higher for plan A or Plan B whatever it is, what happens if the discount rate I changed a little bit? Right instead of 8 percent what if it was 7 point 8 percent, so Excel offers us very easy ways to start looking at you know how to do sensitivity analysis right.

So there these data tables that you can use, so if you just scroll down the entry sheet a little bit you will see something like this right you will see your one way data table ok, so here what we want to do is in this yellow box here we are going to again calculate the difference in NPV is right, so because that is what telling me which is better or not. So I am going to put in the same formula here right I am going to say NPV A minus NPV B, so I am going to get that same 5 point 66 here I am going to say NPV A minus NPV B all right.

So I get my 5 point 66 there also alright and here in this column are the various discount rates for Plan B that I want to do some sensitivity all right, so Plan B had a discount rate of 8 percent but I am saying what happens if I went from 8 to 10 percent or whatever rate right, so the way to do this is if you just select both of these cells right and then you drag the whole thing all the way down till the end of the yellow right you will find that Excel just continues with the same progression right if you took just 1 cell and dragged it down then Excel would have put 10 percent everywhere, if you take two cells and you drag them down because one is 10 and the other is 9 point 9 Excel does the same thing, so you go 9 point 8, 9 point 7 you can also type it in if you like but right.

So essentially the point is I am going to do a sensitivity on all of these in other words I am going to calculate NPV A minus NPV B right but with discount rates at 8, 8 point 1, 8 point 2, 8 point 3, 8 point 4 etcetera right, so the way I do this right is essentially using what we call a data table right so this is what I wanted you to do I want you to select this whole block both rows and columns right select the whole block and then you go to most likely it will be in data right within data you should have something that says what if analysis right irrespective of which version you are using something like that and within what if analysis there is something called data table all right.

So if you click that you'll see a dialog box like this coming up right, so this is what we call a column based data table right because it is my data on the column that is vary right so forget the row input cell right the column input cell right is the cell that I am vary what is the cell that I am vary? What is the parameter I am varying

Student is answering: C copy.

Professor: No, then what is the name of the parameter?

Student is answering: Discount rate.

Professor: It is the discount rate right, the discount rate is here right on top this is the discount rate for Plan B right, so what I am saying is I want to vary that parameter right so what this means is I am varying that parameter right the discount rate for Plan B I am varying it 10, 9 point 9, 9 point 8, 9 point 7 whatever up to 8 and for all of these variations calculate NPV A minus NPV B ok, so if I say ok then I should get something like this right again all of you should get the same thing right because there is just a calculation then there is no randomization no uncertainty right so in other words I have done a sensitivity right and I found out that if Plan B is interest rate increases the differential between A and B keeps increasing right.

So you know to the point where if plan B is discount rate is 10 percent the NPV of A is more advantageous by 35 point 02 right you guys able to get the data table right, we are able to select all of those right, go to the data table and sort of say column, the column input cell I am varying is the plan B discount rate recalculate NPVA minus NPV B ok, let me know if you are still working on it, just raise your hand because if not we will go to the next step yeah.

Student is questioning: (())(24:57).

Professor: Ok, so and you have all of this on the left that it goes 10 point 10 percent whatever 9 percent etcetera and you did you select exactly this rectangle starting from plan B discount rate the two columns down ok just try hitting F9 we have had this problem before there are some I do not know why some versions of Excel loaded on some peoples computer does not seem to work.

Student is questioning: (())(25:34).

Professor: Try again, hit F9, Sunoj, Arvind you guys are just 5 point 66 again let us just try it one more time hit F9 and see if there is a change.

Student is answering: Yeah.

Professor: Which F9 worked?

Student is answering: Yeah.

Professor: Yeah just hit F9, it is a recalculation functions so sometimes it so yeah, Sunoj f 9 worked, ok. Just check are you selecting exactly this rectangle right all the way down right and did you put in the column input cell ok and the column input cell was that right and you are getting 5 point 66 everywhere and if you hit F9 nothing changes ok, well hopefully that is fine I mean we will it is not critical because we are not going to use this very much but yeah sometimes it happens.

So this is essentially varying one parameter but Excel also allows you to vary two parameters right so one of our hypotheses for why A was better than B is we felt that A is variable cost was more advantageous to B, so what if A is variable cost and B is variable cost could be changed a little bit? What happened if one came down a bit one came up a bit at what point might you get a break even? Right.

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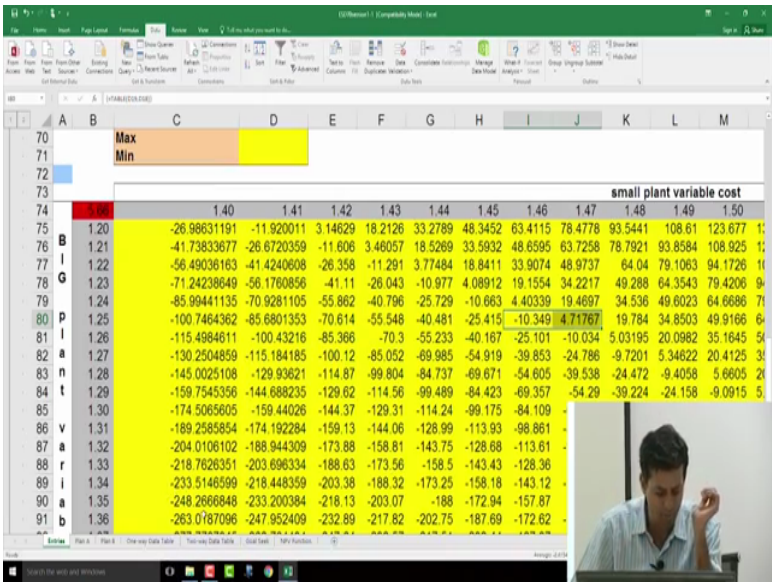

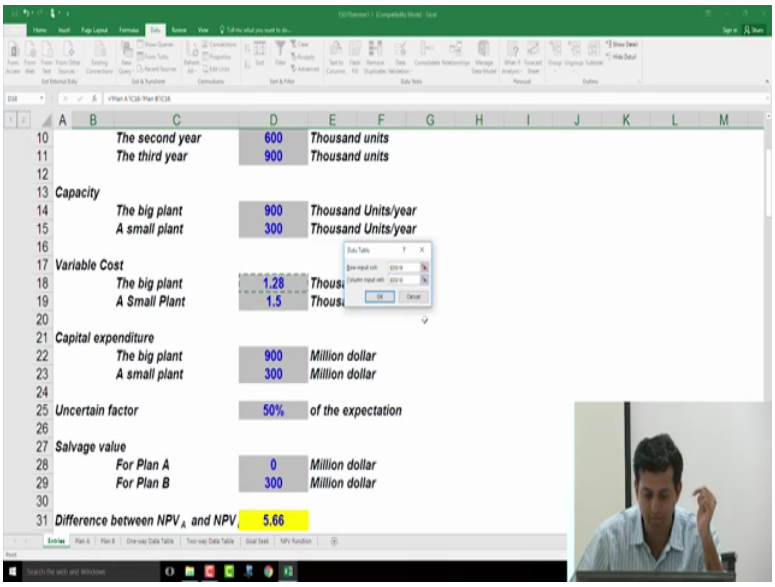

So essentially you have here if you scroll down a little bit more you have something called a two way data table right and the two way data table as you can see on the column I am having the variable cost for plant A and I am varying it from 1 point 2 to 1point 45 the actual cost we took was 1 point 28 but I am varying it from 1 point 2 to 1 point 45 and on the row I am varying this small plant variable cost from so it was 1 point 5 I am varying it from 1 point 4 to 1 point 6 right.

So I am varying these costs a little bit, so I am doing some sensitivity analysis on my model ok so again that the way I calculate all of this simultaneously is pick the entire yellow box ok, so I pick the entire yellow box ok I do the same thing I go to what if analysis data table now this is a two way data table, the row input cell is the row input cell is the unit the variable cost for the small plant, the column input cell is the variable cost for the big plant and I just say ok and I should see something like this ok, so just select the whole table right starting from that red box up to the end right and then you would select that whole so that what you have entered in the red box is what it is calculating right.

So in the red box if you click on the red box you will see that it is plan A C16 minus Plan C B is C16 which is the NPV is, so it is recalculating that by varying both of these parameters right simultaneous so you get all the combinations, so of as 20 by 20 there is 400 cells there right and then you can start looking at there are also goals see under the what if analysis there are also goal seek functions right where it tries to say look can you set a particular value variable to 0 and calculate at what value should another variable take for this to become 0 etcetera but you can sort of eyeball this and you can start looking at where you might start

getting to the zeros right, so maybe at a big plant variable cost of 1 point 25 and a small plant variable cost of 1 point 465 you know I might come to a 0.

So you can figure out what your breakeven points are, at what point does it make sense to use the small plant right with regards to this ok, everyone able to get something like this, all right. So this is the kind of analysis that most consultants do ok, so I have developed a spread sheet I have come up with a net present value and then I do some sensitivities right I take one variable and I say oh what if it is not 8 percent whatever it is 9 percent right and I do multiple or I can vary two simultaneously ok and then I can maybe make some decisions I think later on I am not sure if this is automatically there but you can you know if you just copy all of these entries you can even graph them think if you yeah.

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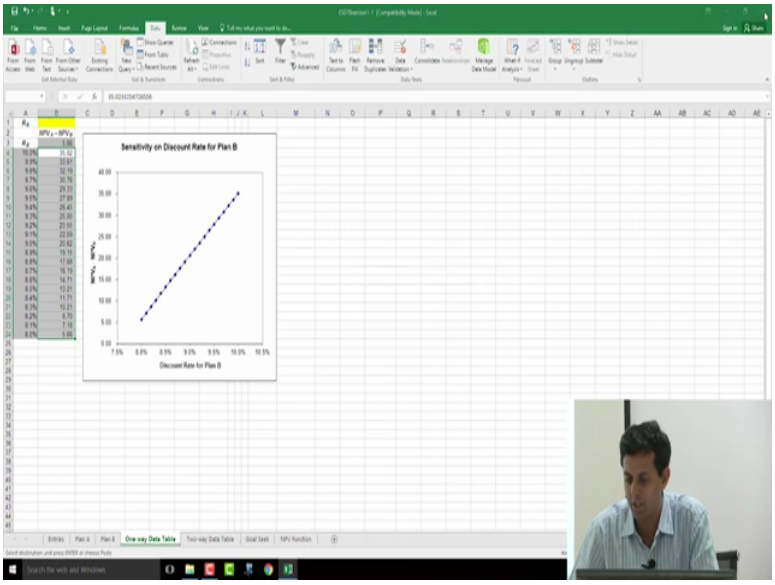

So you can even graph them and see all of that all right but what we want to do is so but this assumes a relatively static universe right, it assumes that whatever I mean of course we have done some sensitivity but it assumes relatively (stat) relatively statistic (())(30:55) with regards to stasis with regards to demand and so on right. So we want to go up one more level and start introducing some uncertainty into our models ok, so for that what I want you guys to do is I want you to get out of the spread sheet ok.

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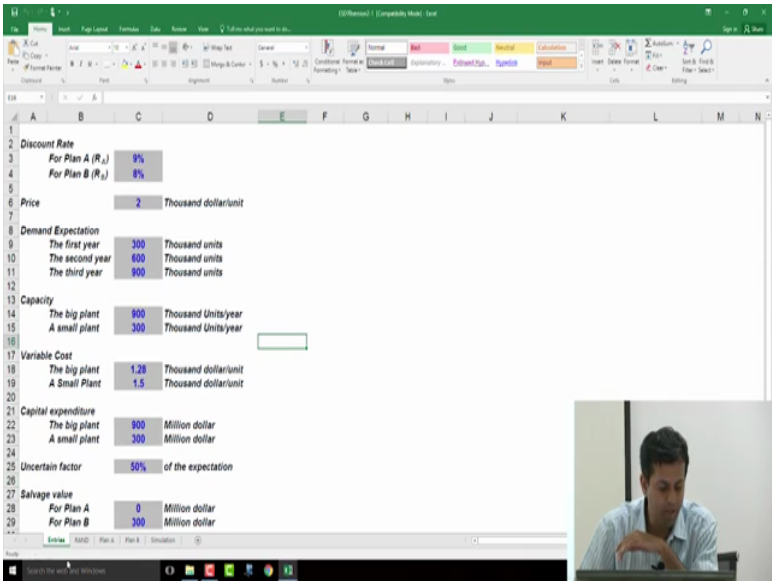

And open 2 dash 1 right so get out of 1 dash 1 and open 2 dash 1, 1 dash 1 is just essentially what consultants do right build a model, do some sensitivity, come up with analysis but there is really no randomization in the model ok, ok let me know when you opened up 2 dash 1, how we are doing on 2 dash 1 everyone is opened anyone not open raise your hands like everyone is got 2 dash1 ok.

Now here what we are going to do is we are going to say look how do you know that demand will be 300, 600, 900 ok what if demand was a bit variable what was not and variable not in terms of this these nice increments what if it was a random right what have you could not really predict it ok.

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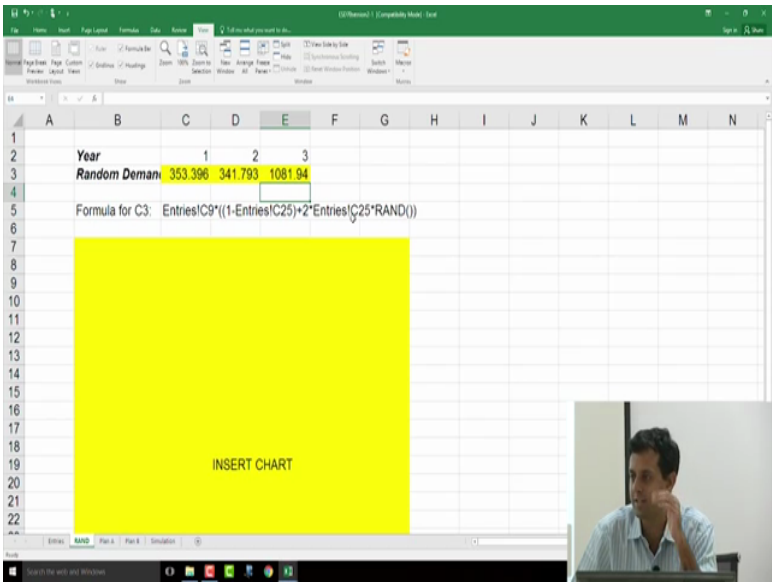

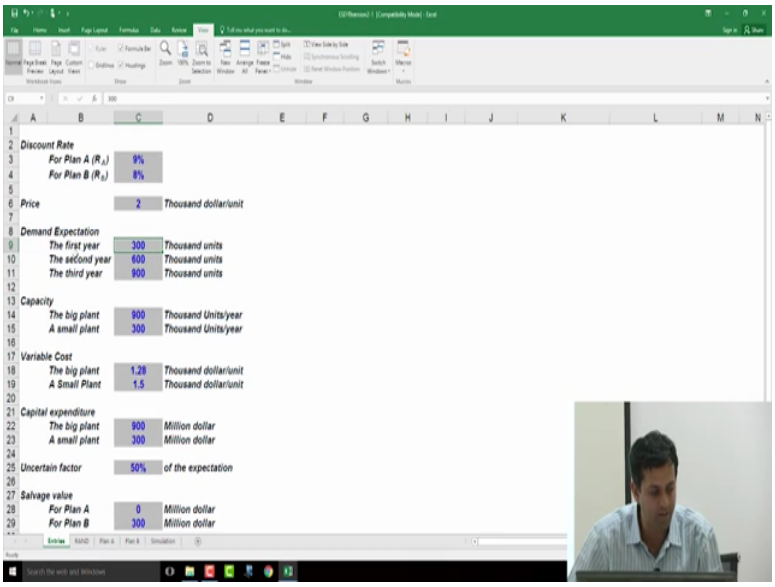

So one way of doing that is if you click on the RAND tab right is using something called a RAND function that Excel has ok. So the RAND function allows you to sort of very randomly all generates random numbers between 0 and 1 ok, so what I want to do now is that one if you go back to the entry spread sheet right now you see an uncertain factor of 50 percent of the expectation ok.

So what I want to do so what I mean by that is I mean that in the first year my mean is 300 but there is a 50 percent deviation either way in other words the actual demand can be anywhere between 150 and 450 right, second year the mean is 600 but it can be anywhere between 300 and 900 right 50 percent this way 50 percent that way, third year it is 900 is the mean but of the distribution but it could be anywhere between 450 and 1350 right, so I might demand now has a range right because I cannot really predict accurate demand in real life okay.

So what I want to do now is I want to rather than just taking 300, 600, 900 I want to randomly generate a demand within those box ok and the formula for doing that is you know quite simple use essentially well the formula is here but the way you interpret that formula is you take the lower bound ok then you take the so the lower bound same for the first for your 1 the lower bound was 150 right so we said the demand could be anywhere between 150 and 450, so you take 150 all right as one parameter then you take the difference or your band which is 300 right you generate a random number between 0 and 1 okay and multiply that with 300.

So you get some number between 0 and 300, right I generate a random number between 0 and 1 I multiply it with 300, so I get some number between 0 and 300 I add 150 on to it right so I have my 150 which is my starting point from that starting point I pick a random number between 0 and 300, right so if the random generator generates a 0 my answer will be 150 if the random generator you know gives me a 1 the answer will be 450 right or if the random generator number generator gives me a point 73 or a point 67 or whatever I will get some random number between 150 and 450 right which is essentially what we are seeing in this formula.

The entries at C9 right is what is entries at C9? Yeah so entries at C9 is 300 and what we are saying is ok take the entries and well you can work it out but essentially it works down to the to the same thing so it says takes entries by C9 you know multiplied by 50 percent so you get your 150 and then from that 150 sample right. So one of the things you can do is I mean if you are too lazy to type just cut and paste the same thing so say ctrl C go to this cell say equal to and control V ok, so you get a random number right you should get a random number somewhere between 150 and 450 right and this random number by the way will be different for each one of us right because the random number that it generates is probably this you know tied to you know the time on your clock and then some permutation manipulation of mutation of that sequence or whatever it is right.

So each of us will get a different number the only thing is all our numbers should be somewhere between 150 and 450 right, so I can do the same thing for cell 2 and cell 3 right now the two differences are I mean I can drag that in for cell 2 it is actually not C9 it is C10 right the base value that I was trying to sort of work off is the C10 and the entries of C25 is the same for both for all because that is the 50 percent factor.

So in other words it is the same formula for all three cells except that it is entries of C9 entries of C10 and entries C11 right, so for the first year I am taking entries at 3, 9 which is my 300 and I am randomizing around that your two I am doing entries at 310 which is 600 I am randomizing around that yeah so 1 minus entries at C25 is 50 percent so I take my entries of C9 multiplied by 50 percent right so I get my base of 150 or 300 or whatever and then I sort of take that 50 percent multiplied by 2 I multiplied which is essentially 1, I multiplied by some random number right and I then take that random number and yeah so added so the product of the random number and the mean entry I then take and added to the or the initial starting point to get my random row, so it is the same sort of logic, ok.

So essentially are what we have done is we have no randomized demand, so it is now 311, 583 point 569 and 748 point 947 it is not a very nice and clear 300, 600, 900 ok, first year it is a bit higher than expected year two and year three it is a bit lower than expected right, so if I click enter oh good so all I have to do is click and enter and it recalculates ok and you guys can play with it you can do F9 is as much as you like until your finger starts paining and you will get new random generations ok. Now for and it will all be different for all of us.