Manufacturing Systems Management
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Lecture - 17
Part subcontracting, Incremental cell formation

In this lecture we continue the discussion on Parts of Contracting.

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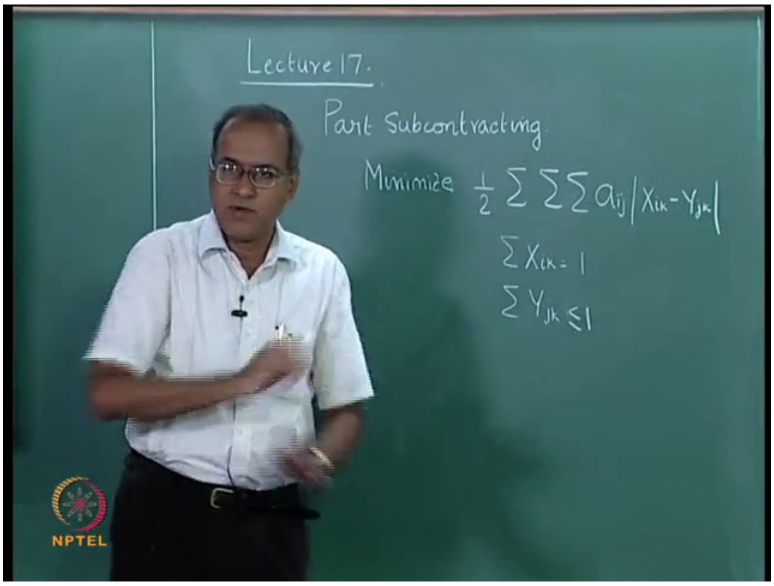

As mentioned in the previous lecture.

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	1	4	5	6	2	3	7	8
1	1	1	1	1				
3	1	1		1				
4	1		1	1				
2				1	1		1	1
5			1		1	1	1	1
6	1	1		1	1	1	1	1

Since there are two groups, we add the constraint $Y_{11} + Y_{12} + Y_{21} + Y_{22} + Y_{31} + Y_{32} + Y_{41} + Y_{42} + Y_{51} + Y_{52} + Y_{61} + Y_{62} + Y_{71} + Y_{72} + Y_{81} + Y_{82} \leq 7$

The optimal solution to the problem is given by $X_{11} = X_{31} = X_{41} = X_{22} = X_{52} = X_{62} = 1$.

$Y_{11} = Y_{41} = Y_{51} = Y_{22} = Y_{32} = Y_{72} = Y_{82} = 1$ with $Z = 11$.

We also have $Z_{161} = Z_{262} = Z_{361} = Z_{461} = Z_{551} = Z_{552} = Z_{611} = Z_{612} = Z_{641} = Z_{642} = Z_{662} = 1$ giving an objective function value of 11.

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If we have a final solution like the one that you see here on the picture, there are 5 inter cell moves. And if we are going to use parts of contracting as a way to minimize inter cell modes, the first part that we can try and subcontract is part number 6. So, we try to modify the Bhakta's formulation in such a way that we include parts of contracting into the formulation and we can try and solve it, rather than solve it without part subcontracting and from the optimum solution or solution using any algorithm we try and identify which are the parts to be subcontracting.

So, the Bhakta's formulation has an objective function of minimizing the inter cell moves X i k equal to 1 if machine i goes to group k and Y j k equal to 1 if part j goes to group k. The original Bhakta's formulation will have sigma X i k equal to 1 which means each machine is assigned to one group and sigma Y j k is equal to 1 where each part is assigned to one group. Now, with part sub contracting being included then all the parts need not be assigned to cells while some parts are subcontracted. So, this can be written as Y j k less than or equal to 1 which indicates that it could be assigned if it is 1 then it goes into a group, if it is not 1 then it does not go into the group it takes 0 and it is subcontracted.

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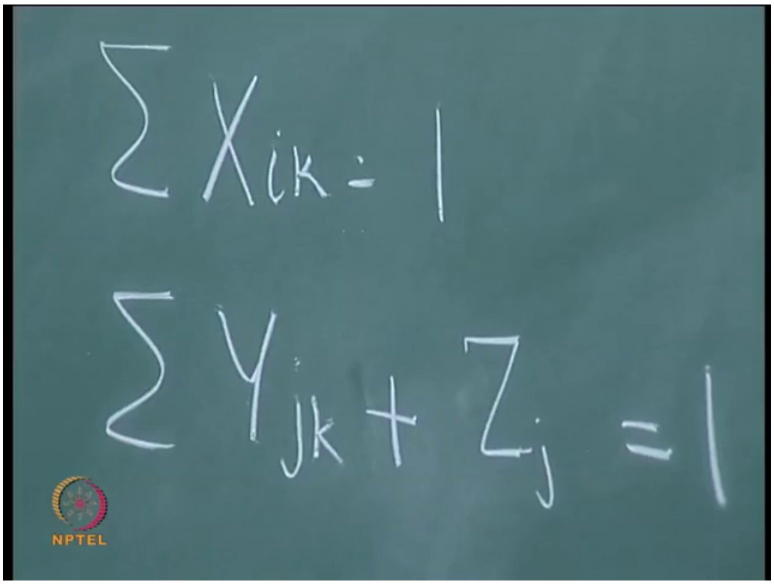

So, one way to do it is to write like this or another way to do it is to say plus some Z j is equal to 1. We have already used the notation Z in the in an earlier lecture when we linearize this absolute value term. So, now, we if we do this we have to use a different notation other than z 2 linearize, because we have used Z here and this Z should not be confused with the other Z that can happen when you linearize or we could even say S j equal to 1, if part j is subcontracted representing S for subcontracting.

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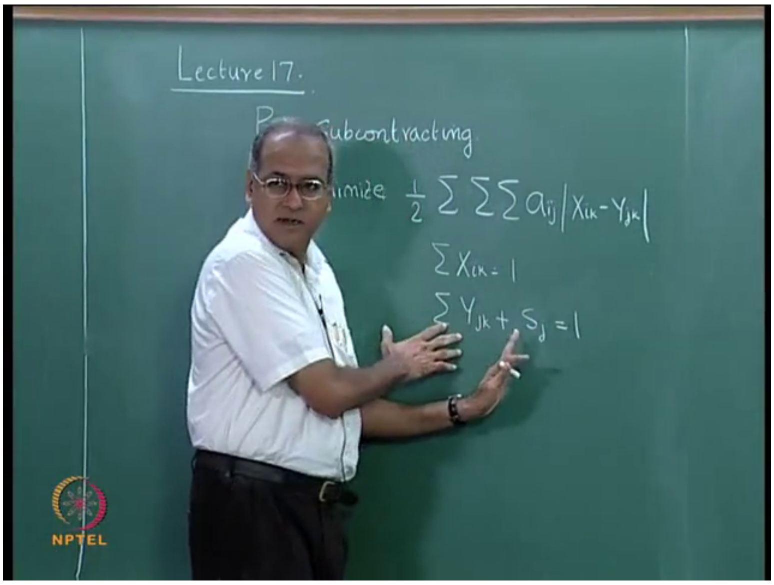

Again X i j X i k Y j k are binary. Now we should look at some other possibilities that can happen now because of the subcontracting can we get into a situation where all parts are subcontracted in the solution, we have to ensure that that does not happen.

For example: can we have a situation where all 8 parts are subcontracted, because this allows every part to be either put into the cell or to be subcontracted. We have not explicitly added a cost of subcontracting into the objective function, if we did that then it will not take all of them towards subcontracting. So, now, we have to check whether such a possibility exists suppose all the 8 parts are go to subcontracting then no part goes into the cell and the objective function value here, because this a i j will be 1. For every a i j that is equal to 1 there will be some X i k that is 1 because each machine is allocated to a cell.

So, this will throw out as many inter cell moves as the number of ones in the matrix if all parts are subcontracted. So, ordinarily it will not allow all parts to be subcontracted because this solution with 5 inter cell moves is a better solution than saying all parts are subcontracted and therefore, we will have that many inter cell moves as the number of ones; because if all parts are subcontracted all these are 0, but all these X i k's will have to take a value 1 from where and these a i j's take value 1 at the relevant places.

So, this will throw up a whole lot of inter cell moves. So, in a way it is good that we have the formulation this way and this should be enough. Sometimes we might like to restrict the number of parts that are subcontracted. So, we could simply add another constraint which is sigma S j is less than or equal to some capital P or whatever to say that not more than 3 or 4 parts can be subcontracted. So, that will also ensure that too many parts do not go to subcontract again this is a kind of an optional constraint all these are enough to take care. Now in the slide what I have done is I have said that.

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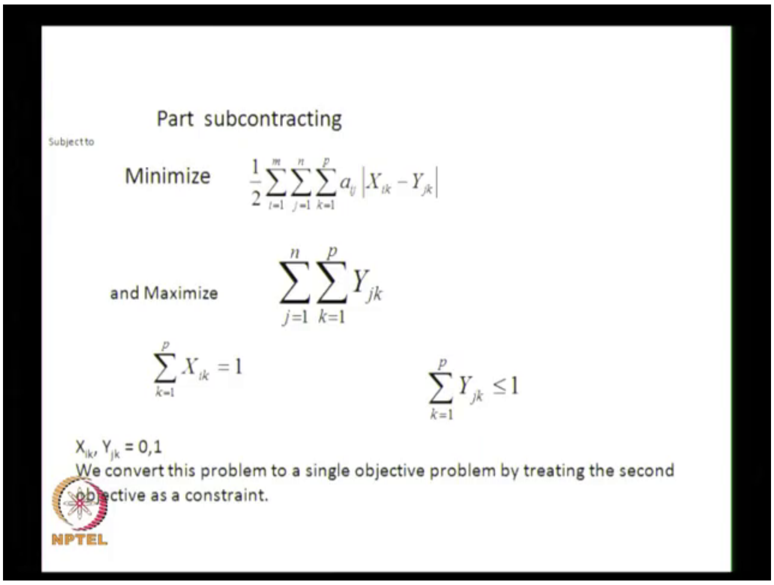

Now, when you give this condition, this is written from the constraint sigma Y j k less than or equal to 1 now that is rewritten as plus S j equal to 1.

So, if we want to look at that constraint, we could try to either minimize the number of parts that are subcontracted or try to maximize the number of parts that go into the cell. So, the corresponding objective is written as maximize Y j k. So, now, this looks as a 2 objective problem. Two objective problems are also not very easy to solve. So, it is to consider one of them as a constraint. So, when we take this as a constraint the maxima is sigma Y j k as a constraint Y j k greater than or equal to some number, which is the same as minimizing the parts that are subcontracted and saying that not more than P parts will be sub contracted. So, this formulation is the same as that shown in the slide.

So, as I again said this is only an optional kind of a constraint, even without this the problem does not lend itself to a trivial solution, sometimes change of something from an equation to an inequality can tweak the entire solution that does not happen in this case. It does not say that all parts can go to subcontract, it is still economical from an inter cell move point of view to have a reasonably large number of parts made in the cell and some of them being subcontracted. So, this is how part subcontracting happens and this is how Bhakta's formulation is modified. Similar modifications can be made in the P median formulation also, but we are not going to describe such modifications here. So, this is a constraint which says that a maximum of only one part can be subcontracted.

So, either it can be written here as S 1 plus S 2 plus S 3 plus S 4 plus S 5 plus S 6, S 6 plus S 7 plus S 8 less than equal to 1, the other way to write is y 1 1 plus y 1 2 plus y 2 1 plus y 2 2 etcetera has greater than less than or equal to 7. So, we would like to have actually greater than or equal to 7, will ensure that no less than or equal to 7 will ensure that some parts are sub actually we want to maximize that. So, we should say there as greater than or equal to 7. So, the 8th part will go to subcontract and it will do. So, the optimum solution is given with part number 1 1, 3 1, 4 1, 2 2, 5 2, 6 2 equal to 1 and with Z equal to 117 2 8 2 equal to 1 with that we will now see that 6 is missing. So, 6 is subcontracted part number 6 is subcontracted in this.

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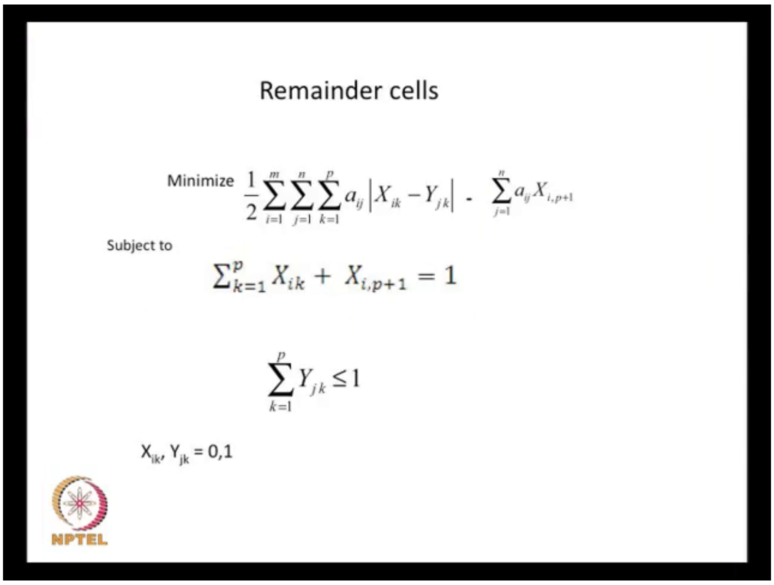

So, having seen some of these ways to minimize inter cell moves, we look at one more aspect to cellular manufacturing which we are going to introduce here as reminder cells.

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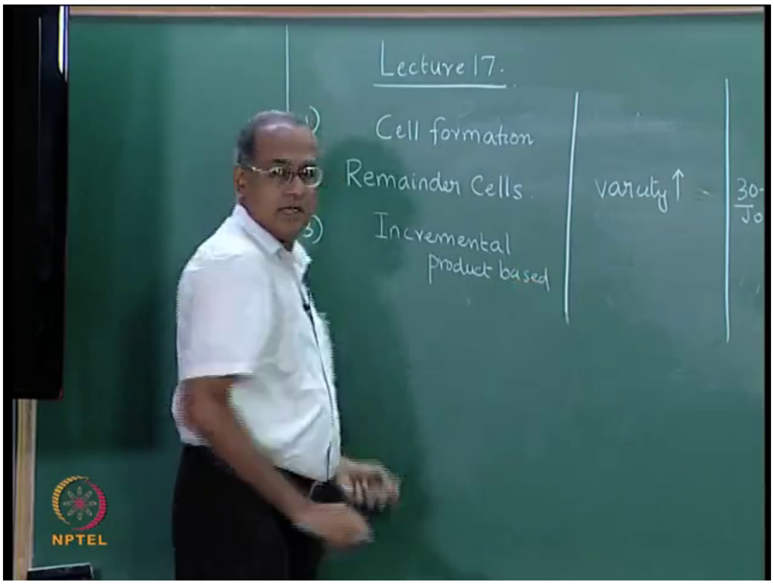

Now what our remainder cells and why are we talking about remainder cells. Now when we looked at the cell formation that we have seen, starting from production flow analysis, we now take data from an existing plant as to how the parts are manufactured. And up to now then in the production flow analysis or rank order clustering algorithm or the basic doctor and p median formulations, we have assigned every machine to one group and every part to one group. Sometimes you have assigned more than one machine also to more than one a machine can figure in more than one group with multiple copies assigned to each.

Now, this we can call as some kind of complete cell formation or normally called cell formation.

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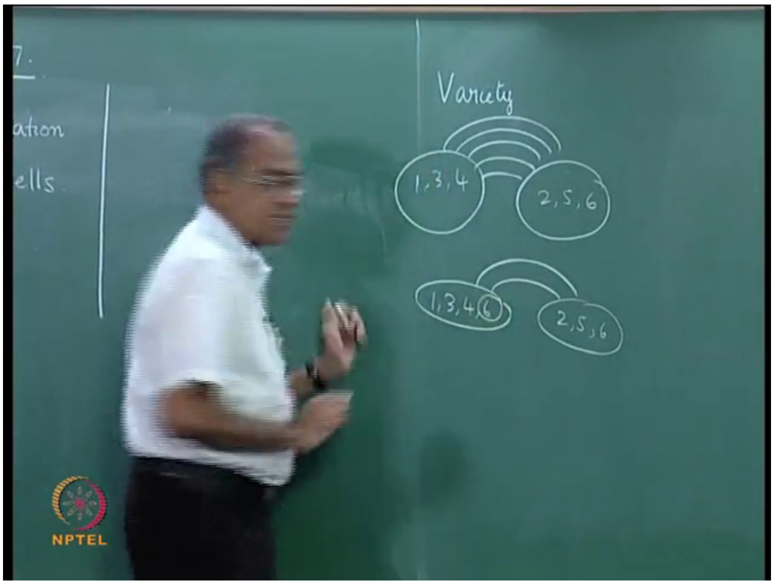

Now, let us also look at what happens when variety increases in a cell. Now what is variety?

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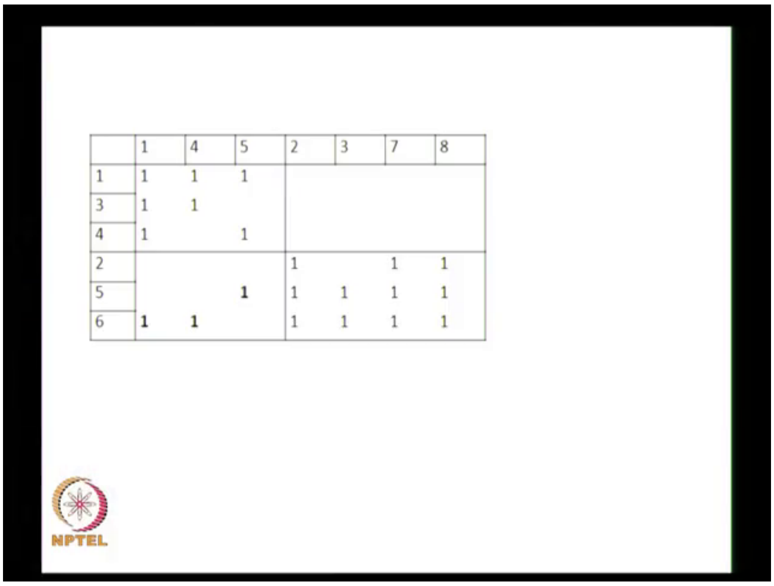

	1	4	5	2	3	7	8
1	1	1	1				
3	1	1					
4	1		1				
2				1		1	1
5			1	1	1	1	1
6	1	1		1	1	1	1

If we look at an incidence matrix like this, let us say these are 8 distinct parts that are produced in the factory not in the cell, but in the factory there are 2 cells in this solution. Now if we introduce a ninth part. And if the ninth part which is represented as column number 9 is say identical to column number 1. If it is identical to column number 1 including the column number 9 into the cell formation would automatically put column number 9 or part number 9 along with 1 4 and 5 because it is identical.

So, it will automatically go to the group 1 3 and 4; except that additional capacity may be required in the group 1 3 and 4, additional capacity for machines may be required. But if column number 9 is very different from 1 to 1, 4, 5, 2, 3, 7 and 8 let us say then automatically column number 9 brings a certain variety into the system. So, variety is represented by the columns is not being identical columns being very different. So, when variety comes into the picture, already let us say this has 3 inter cell moves in this solution this does not show part number 6 this is a solution at the end of part subcontracting. But if we go back to a more familiar 1 which is this which has 5 inter cell moves and if I am bringing in a part number 9 now there are going to be more inter cell moves coming out of part number 9.

So, as variety comes in as products change over a period of time, which results in more and more newer parts coming into the system and each part being represented by a column as products change product variety changes, part variety changes and this will result in more inter cell moves. So, one solution is machine duplication; another solution is revisit and recreate cells, the third is to allow inter cell moves. Now once we start allowing inter cell moves we lose control, the primary reason for implementing cellular manufacturing is lost when we start allowing too much of inter cell moves. So, what we do here is for example, in this; if we take this as an illustrative solution even without an additional part number 9 with the existing system.

Now, we have one machine group with 1 3 and 4 the other machine group with 2, 5 and 6 and there are 5 moves here if we allow machine duplication then the solution will be 1 3 4 and 6, 2 5 and 6 and there are 2 moves which are here. Now this is going to be a little costly because this is an extra machine that I have to bring in.

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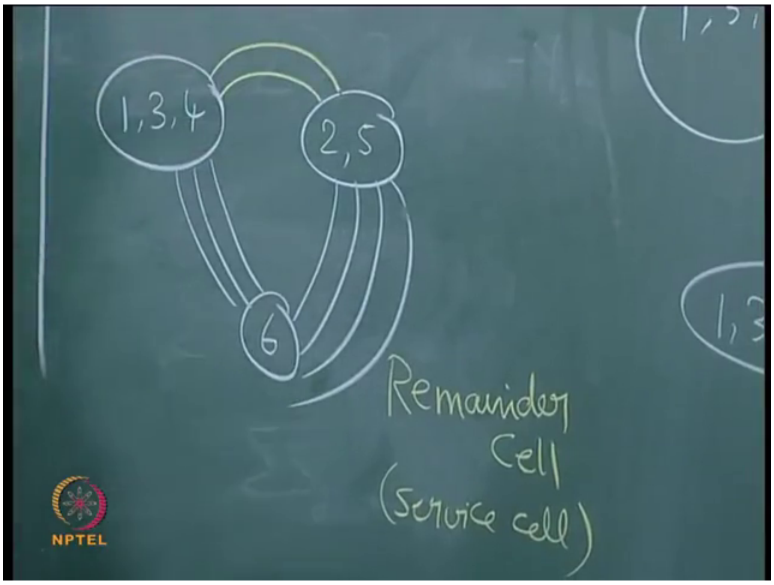

Now suppose I say that, I have 1 3 and 4 here, 2 and 5 here and 6 here 6 here then i am going to have 6 is machine number 6 6 is machine number 6. So, I will have 3 visits from 1 4 and 5, 3 visits from 1 3 and 4, I have 4 visits from 2 3 7 8 and I will have 2 visits between these 2 .

In a way this solution is the same as this solution, if I leave this portion. So, instead of creating buying an extra 6 and putting it here I am just pulling this 6 out and doing this. Now one way of looking at it is now I have 3 plus 4 7 plus 2 9 inter cell moves the other way to say that if I am not counting these I have only 2 inter cell moves and I have not added a machine. Now I call this as a reminder cell or some kind of a service cell where there are only 2 cells parts can move from the cells to the service cell and go back these are not counted as inter cell moves whereas, moves only from these are counted as inter cell moves. Now such an idea is called a service cell or a remainder cell.

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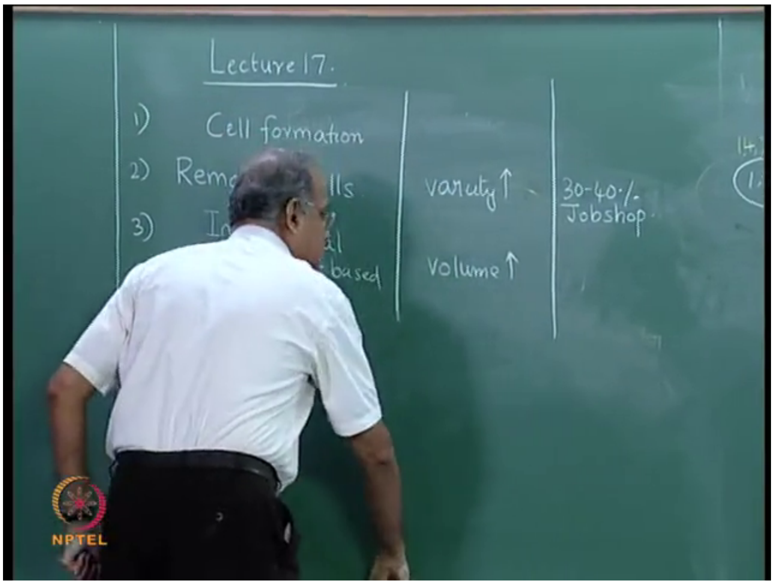

Now, this is one way of representing it and this becomes significant when variety increases. The same idea is expressed in the literature by saying that certain portion of the manufacturing system is grouped into cells and certain portion remains as a job shop or as one large service cell.

So, this is something like saying 30 to 40 percent of the machines will act as a job shop while the rest of the machines will act as or will be grouped into cells. Now there are 2 ways of looking at the pictures that I had drawn here, one is to say that if I create a reminder cell my inter cell moves reduce, but my moves into the remainder cell increases; so whether its 2 moves are 9 moves or 11 moves.

Nine moves 2 plus 2 plus 7 9 moves, 7 moves were here 2 moves were there. So, whether its 2 moves of yellow or 2 plus 7 9 moves. So, if we do not count the moves into the inter cell now to the remainder cell, then we have only to moves. But we lose so much of ownership and control the only difference is the service cell or the remainder cell will look at each of these cells equally with equal importance and it since it does not have any part ownership it will not treat any part as something coming from outside.

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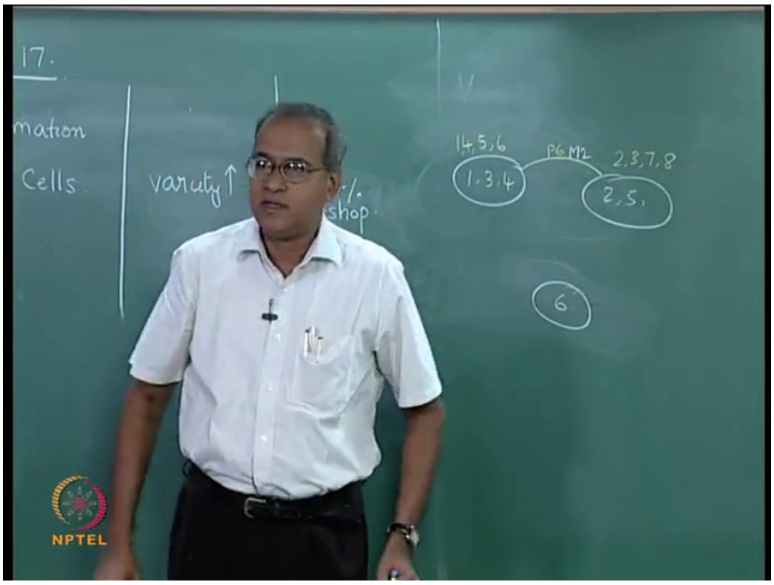

For example if I do this if this is my remainder cell in terms of machines; now in terms of parts 1 4 5 6, 2 3 7 8.

Reminder: cell does not own any part parts are assigned only to the g t cells or the normal manufacturing cells. Because this does not own any part it treats both these equally, it does not treat apart visiting here as an unwanted burden on the cell whereas, if there is an inter cell move here with part 6 going to machine 2, p 6 6 going to M 2. M 2 is here now this cell will treat this p 6 as something that does not belong to myself, but this part is coming for machining and particularly if this cell is going to be viewed as a profit making entity. And because this part is owned by this cell whatever revenue or profit generated, here let us assume is not going to be added to this or even that fraction is not going to be added then this inter cell move will be treated as an unwanted commitment of this cell to something else.

Even though in principle we should not be thinking so, that the organization in total is benefiting by it, but remainder cell does not have any part allocated to it therefore, it does not treat any of these as inter cell moves or as something which is not its own that it is performing. At the same time move is a move so, there can be delays and so on. So, we will lose some control, but we have the advantage of not duplicating the machine machines are kept as a common facility. So, that is idea of the remainder cell, but in just to complete this. So, one is cell formation were all machines are put to cells 1 is a remainder cell formation, the third we call as incremental cell formation or product based cell formation. So, here the cells are formed based on products themselves. So, a complete product is made within the cell, whereas here we talk of machines and parts here we talk of part product parts belonging to a product and machines.

So, here you all variety is slightly higher here the volume is slightly higher so that we can create cells to make 1 or 2 parts. Here we have both variety and volume mid, mid volume, mid variety here. So, these also are treated in terms of various classifications of the plants. Where the literature has said that this is a slightly large variety manufacturing where 30 to 40 percent go into a job shop.

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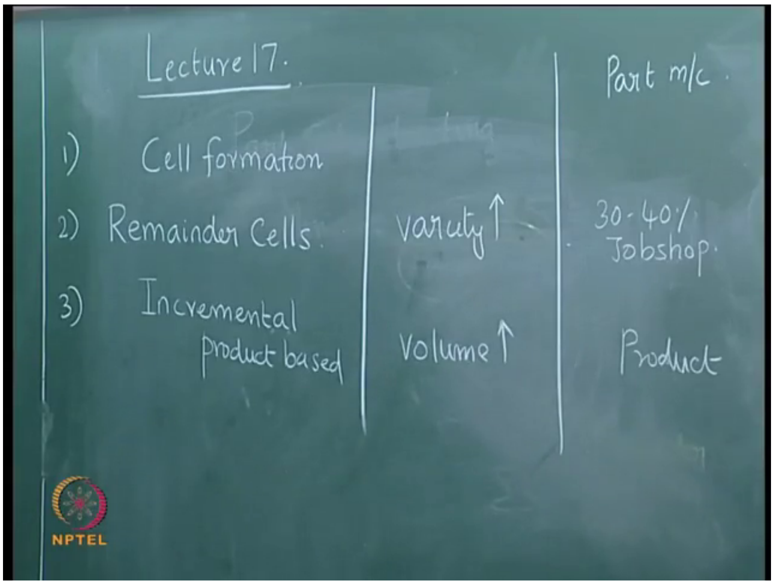

This is typically part machine cell formation; this is product machine cell formation. So, we really want to classify cellular manufacturing further into 3 types, one is the normal machine component cell formation where the products are slightly larger in terms of size involve specific common assemblies parts are made into cells, parts go to the various assemblies. Finally, for a particular product we may require parts coming from different cells and the product is assembled and produced.

This is applicable to the same scenario, but there is a large variety therefore, we are unable to create independent cells which will which will make a family of parts therefore, we have a common facility where some of them will go into a common facility you may call it a job chocolaty remainder cell and so on. This is a case where the products are little smaller in size, where is sufficient volume the cell is created and everything from this cell will go to an assembly which is very close to or even within the very close to the cell or in the same area as the cell is and the complete product will come out by pulling out from this cell. So, this classification also is there in the literature. So, with this introduction we will now see the remainder cell, after which we will see incremental or product based sets. So, if we go back to the remainder cell.

Once again we can modify the Bhakta's formulation for the remainder cell. So, Bhakta's formulation will be like this.

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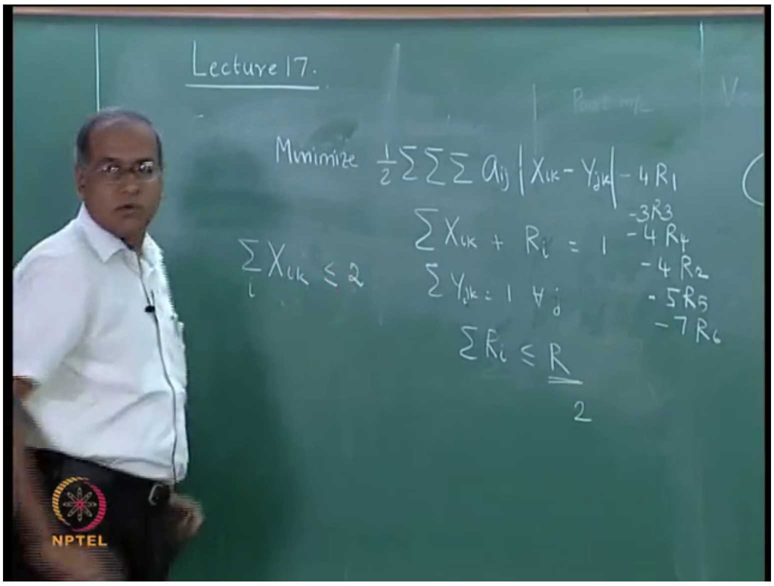

Minimize inter cell moves. The earlier version every machine has to be assigned to a cell; now the machine can either be assigned to a cell or can be assigned to a remainder cell. Just like in the part subcontracting either the part can be made inside the cells are can be made outside the cell. So, in a similar manner we will say X i k equal to 1 is now written as plus some R k equal to 1 if our R i equal to 1 if machine i goes to the remainder cell alright R i equal to 1.

So, next thing we have to ensure is that all the machines do not go into the remainder cell because we are not going to add the inter cell moves further remainder cell again going back to the example.

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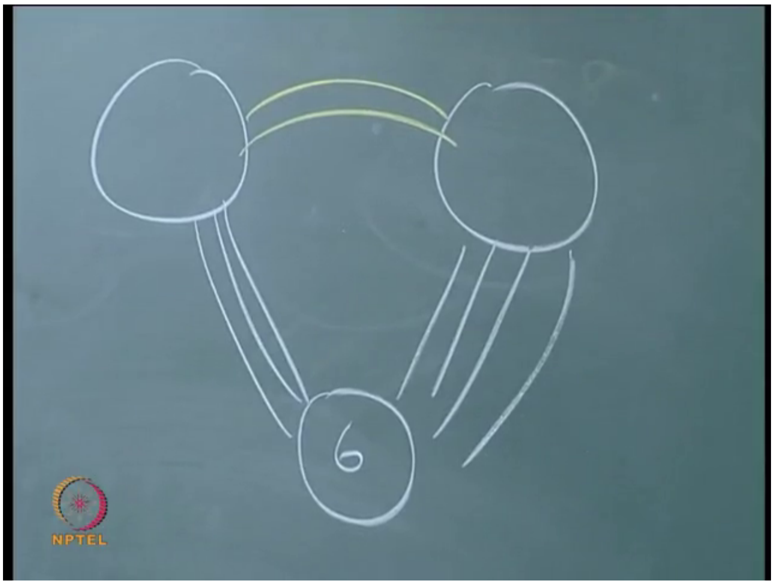

There is this this and this 6 was here, all these moves are not going to be added only these moves are going to be added. So, we should not have a situation where all the machines go to the remainder cell. So, that is taken care by ensuring that, this is taken care by ensuring that there is a size restriction on the remainder cell. So, sigma R i is less than or equal to some R I do not want more than 2 machines in the remainder cell I do not want more than 4 machines in the reminder cell. So, there is a size restriction on the reminder cell.

Now, every parts are not assigned to the remainder cell parts are assigned either here or here. So, this is fine Y j k is equal to 1. Now when machine number 6 is assigned as a reminder cell, going back to the matrix if machine number 6 is assigned as a reminder cell let us see what happens here. Now machine number 6 requires 3 plus 4 7 parts, there are 7 parts that are there for machine number 6. Therefore, there are 7 places where a i j is going to be 1 now the corresponding parts are going to be assigned to cells this is going to be 0 therefore, this is going to overestimate it or it is still going to add those 7 inside. So, we should know then do like we have did earlier. So, we will do minus 4 R 1 minus 3 R 3, minus 4 R 4, minus 4 R 2, minus 5 R 5, minus 7 R 6.

Why do we do this? If machine number 6 goes to the remainder cell then 7 moves are absorbed by the remainder cell. They are not interesting moves, but there are 7 moves that are absorbed by the remainder cell. So, this will be overestimating it by giving us a value of 9 or whatever those 7 will be taken. So, that has to be subtracted similarly 5 goes into the remainder cell, then another 5 moves are going to be absorbed by the remainder cell. So, that has to be subtracted. So, these is this is one full term. So, this is minus 4 R 1 minus 3 R 3, minus 4 R 4, minus 4 R 2, minus 5 R 5 minus 7 r 6 which is shown here as minus a i j X i p plus 1 is your x r subject to the condition X i k plus X i p plus 1 is equal to 1 this is the same as X i k plus R i equal to 1, R i is when it goes to the reminder cell that e X i k plus X i p plus 1 is equal to 1.

So, a machine either goes to a g t cell or goes to a reminder cell. Y j k is equal to 1 is enough we do not need to say even less than or equal to 1, less than or equal to 1 implies it could go for part subcontracting. So, we will restrict Y j k equal to 1. So, that all parts are assigned to the remaining cells. So, when we do this, we could have a solution that has machines 4 and 6 going into the remainder cell with 2 inter cell moves, the final solution will be 1 4 5 6 come here 2 3 part families are impact, but we realize that 4 and 6 go into the remainder cell with 2 inters cells when the remainder cell has a capacity of 2. Let us just check that if we had 5 and 6 go into the remainder cell plus we put a restriction that each cell size should be less than or equal to 2, and 2 machines go to the remainder cell.

So, 4 and 6 go to the reminder cell with 2 and 5 coming. So, this problem is solved with 2 types of restrictions, this is equal to 2. So, 2 machines go into the remainder cell plus we have also put another restriction that cell size we said that in Bhakta's term. So, X i k summation summed over i should be less than or equal to 2 for every cell. So, these gave us the solution with 4 and 5 or with 4 and 6 going into the remainder cell with 2 inter cell moves. Now let us proceed to another aspect of cell formation which is incremental cell formation or product based cell formation.

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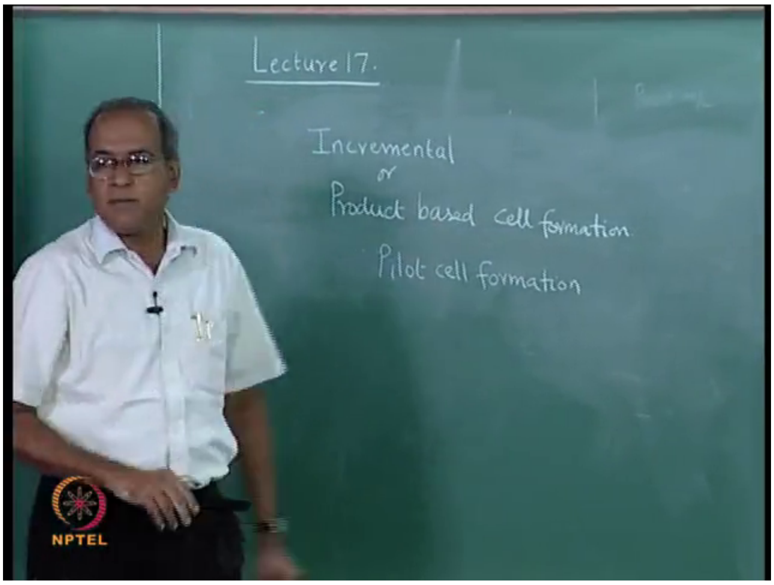

Sometimes is also called pilot cell formation and so on. Same terms are used interchangeably in the literature by different authors sometimes it is called pilot cell formation. Now this happens in 2 different scenarios in manufacturing, one is let us say we start implementing cellular manufacturing and let us say we have carried out a production flow analysis.

Production flow analysis let us say gives us 5 machine cells; first and foremost is it is also very it is not easy to instantly move from a conventional process based layout to a cell layout, because once the cells are formed the machines have to be relocated this would take time. At the same time production should not suffer we cannot for example, stop production for 3 days or 4 days do a complete ray layout and start that is not a profitable proposition for an organization.

So, many times what organizations would do is either on every holiday, they will move machines to other places and over a period of 4 months or 5 months cells will slowly get formed and this and the system will move to a cellular manufacturing system. So, let us assume in such a case we have made 1 cell and then we have to make the other cells. But once that first cell is made that cell is tested how is the cell performing what are the other issues so on.

So, it works with only one cell. So, in such a situation you could call it as a pilot cell formation or first cell formation. The other would be before going through a production flow analysis and finding out machine cells and part families, the organization picks up one product; one product which does not involve too much of assembly and so on or a product that is most profitable either way and create a cell for that product.

So, in such a case also it becomes a pilot cell formation or product based cell formations. Take a product find out what are the parts that are there; what are the operations that are required and create a cell that will make this product. Sometimes the product is chosen more out of convenience for production, sometimes the most profitable product is also chosen. The other times what can happen is there is an existing cell or there are there are existing cells and due to volume and variety the cell capacity is already realized and there are just too much of inter cell moves happening. Now, there is a need to redo this cell and when we redo this cell there will be some interesting changes that will happen, this cell would be expected to produce at a slightly faster output then what it is currently doing.

Therefore newer machines will be brought in. Therefore; again the problem will be one of making one particular cell that caters to the requirements of either one product or very few products. So, we now restrict bring all of these into the classification called incremental or product based or pilot cell. Under the assumption that the volume is large and for a particular product we are going to create a cell. So, we can use the term called product based cell formation. Now with this product based cell formation we will now look at some aspects of this product base cell formation.

So, we are again going to capture it in terms of an incidence matrix to begin with a very slight difference. The matrix remains the same, but the way this matrix is to be red is slightly different.

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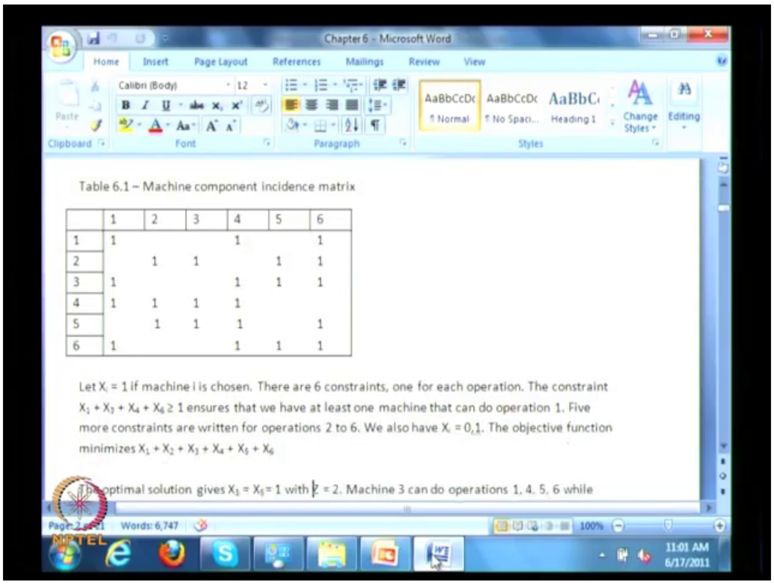

Now, we are going to assume that there are these 6 operations that are going to be performed, the columns now represent operations on the product and this cell is going to make that one product. Now we can use the word product and part interchangeably. So, these 6 columns represent 6 operations that have to be carried out to make a part or a product and this cell is going to make only that part or product, there is enough volume to do that. If we take the first or there are 6 candidate machines that are available, if you take the first operation it can be done in either 1 or 3 or 4 or 6 unlike the earlier incidence matrix, where it has to visit all the 4 machines. Now we make an assumption that this operation can be carried out by 1 or 3 or 4 or 6 it is not an and it is a.

So, the simplest problem is in order to carry out all these 6 operations, what is the minimum number of machines that I require to create a cell. Note that part j does not visit all the machines where a i j is equal to 1, it is enough that part j visits 1 of the machines where a i j is 1 in that column. So, what is the minimum number of machines that are required so that the cell can be formed and this product can be made?

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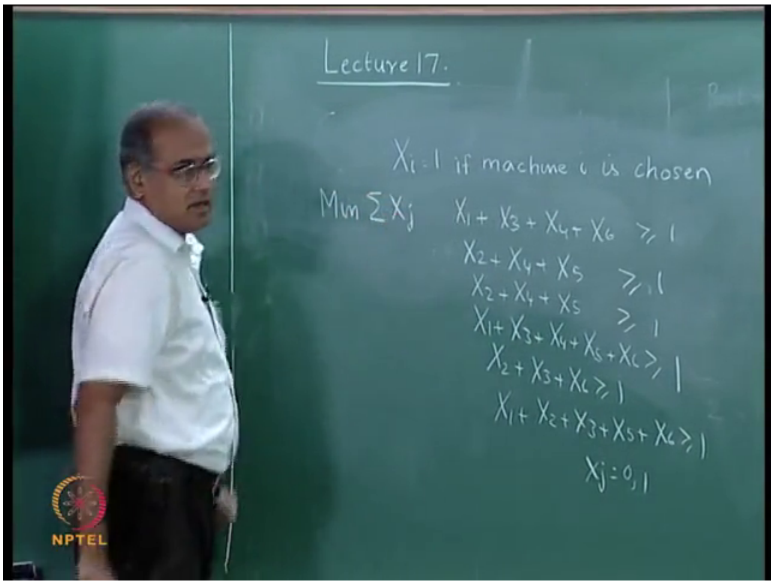

So, we have a simple formulation where X i equal to 1 if machine i is chosen. So, in order to make the first product I should have X 1 plus X 3 plus X 4 plus X 6 greater than or equal to 1. To make the second operation I need X 2 plus X 4 plus X 5 greater than or equal to 1.

To carry out the third operation X 2 plus X 4 plus X 5 greater than or equal to 1. To carry out the 4th operation X 1 plus X 3 plus X 4 plus X 5 plus X six fifth operation 2 3 and 6 and the last operation 1 2 3 5 6; obviously, we want to minimize the number of machines that we choose. So, minimize sigma X j. So, there will be as many variables as the number of candidate machines, there will be as many constraints as the number of operations. The objective function is a straightforward objective function of minimizing sigma x j all right hand side values are 1 and so on. So, this can be solved as a binary IP once again. So, for this particular example this can be chosen the optimum solution is X 3 equal to X 5 equal to 1.

So, for this solution X 3 equal to X 5 equal to 1 and with 2 machines will be able to do. So, X 3 will do operations 1 4 5 and 6 X 5 can do 2 3 4 and 6 can do.

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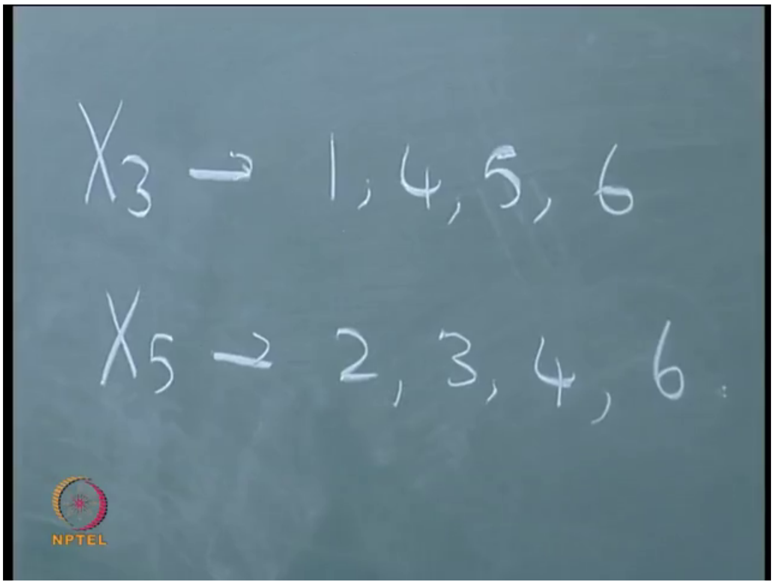

So, now it is up to us to say that we could choose this will do 1 4 5 6 this can do 2 3, this can do 1 5 6 this can do 2 3 4 we can choose anything from this solution.

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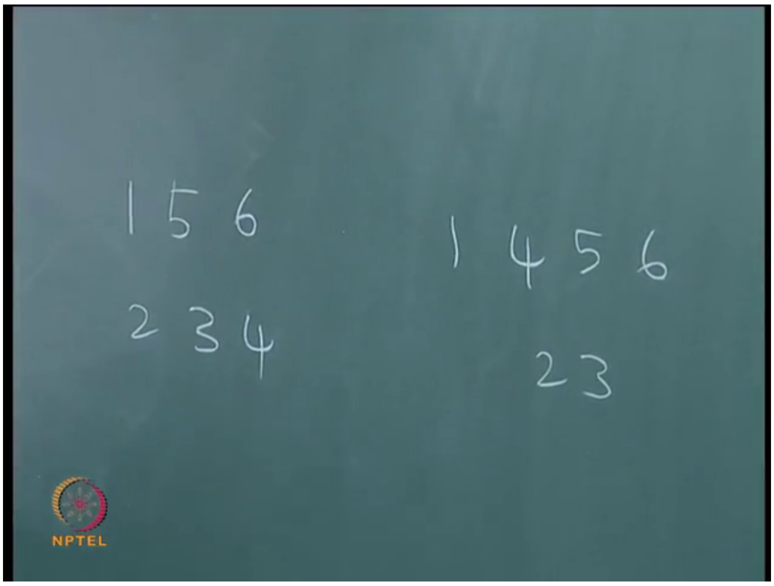

Ordinarily we would choose a solution with 1 5 6 2 3 4 versus a solution 1 4 5 6 and 2 3 ordinarily we would do that. It would also depend on the processing times and so on, but if we want to have better control or if we make an assumption that all the processing times are equal then this would have a processing time of 3 this would have a processing time of 3 whereas, this would have 4 and 2 so the cycle time will be 3 here cycle time will be 4 here.

So, we would choose this instead of this, but all those we cannot do with the data that we have because we have not given the processing times. At the same time simple thumb rule that you balanced by giving equal number of operations will work. So, we need to look at few other aspects on to this problem, one is we should also at some point clearly say that which operation goes to which machine because the process in times may be different.

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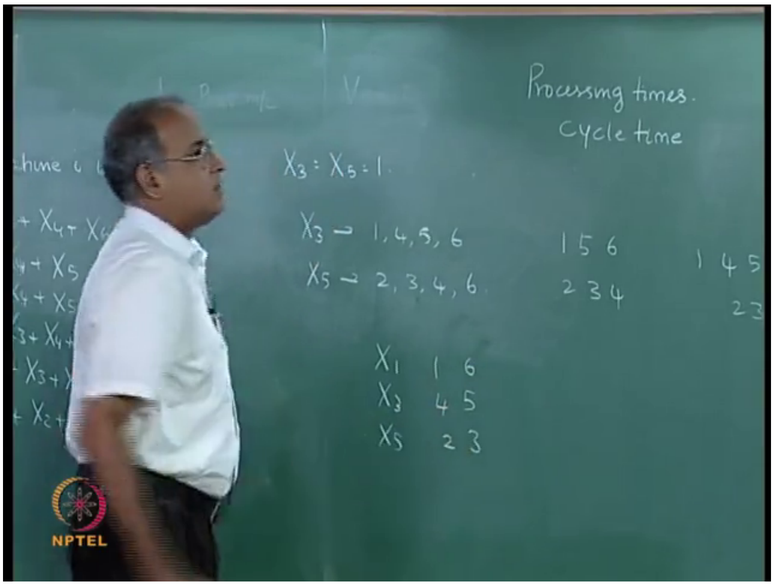

So, we need to bring in processing times into this picture. So, we need to bring processing times into this picture which we have not done. Somewhere we also need to bring cycle time into the picture for example, for the sake of illustration if all the processing times are one, then this configuration would give us 3 and 3 with a cycle time of 3 this configuration would give us 4 and 2 with a cycle time of 4.

Now, suppose we want a cycle time of 2, then we should look at instead of X 3 and X 5 maybe we will look at X 1 X 3 and X 5 maybe we will look at X 1 X 3 and X 5. Where X 1 can do 1 and 6, X 3 can do 4 and 5 and X 5 can do 2 and 3; obviously, we may not be we would not be able to get a cycle time of 2 by choosing this. So, a required cycle time may at the end of the day increase the number of machines in the cell, but we also have to keep something in mind which is this. As a mathematical problem we can simply add a constraint assuming that we have processing times which we have not done here we will see that later, but we could add a cycle time constraint and take it, but we also have to understand that this cell when made has a realistic life of about 2 years, 3 years, 4 years, so on, whereas the required cycle time can vary every day depending on the daily demand of the product.

So, one has to keep the cycle time within a realistic number, which can take care of peak demand or lean demand because if we do it for very tight situation then we create a cell with more machines and on days when we do not require too much of that there will be under utilization. So, there is always the stead of between cycle time and under utilization cell, size and under utilization and so on. So, we will be required to look at processing times cycle times, we might also want to look at cost. Sometimes these 6 machines could be existing machines; sometimes we would like to create a cell with completely new and bought out machines.

Now when we do that the solution may change if instead of minimizing x j to minimize c j x j for example, machine 3 may be a very costly machine and 3 may be substituted with some other machine here.

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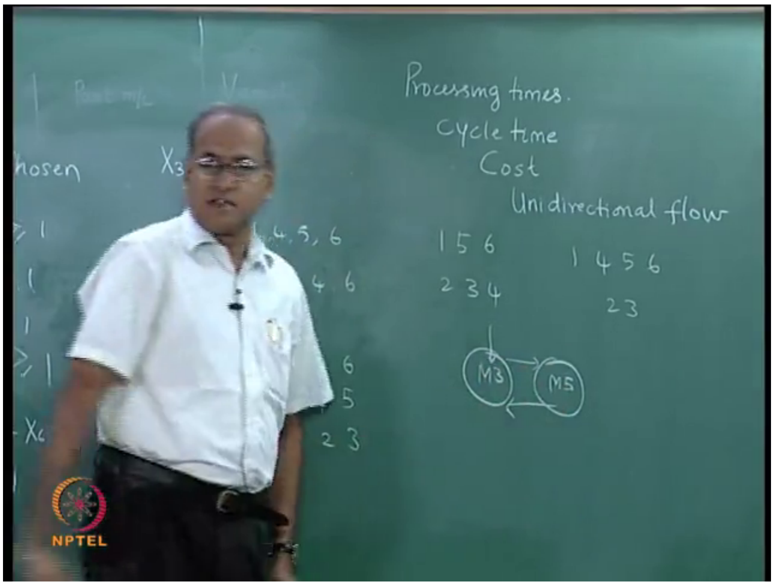

So, cost also has to be looked at and last, but not the least unidirectional flow has to be looked at. If we assume that to make this part or product we need to follow the operation sequence 1 2 3 4 5 6, then this does not give us unidirectional flow because if we have M

3 and M 5. So, M 3 does 1 it comes here, then 4 2 3 4 it goes here 4 5 6 it comes back. So, this is not unidirectional flow similarly this also is not unidirectional flow. So, unidirectional flow may give us a different configuration, unidirectional flow can simply give us M 4 and M 3.

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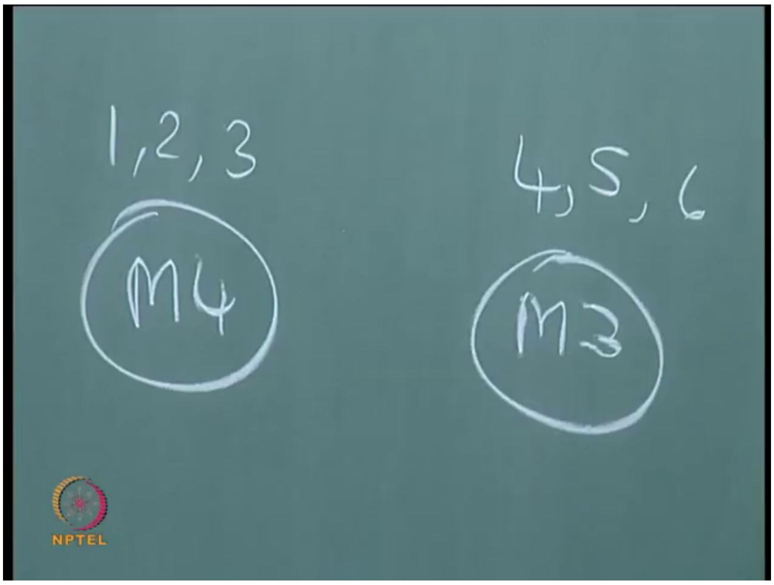

With M 4 doing operations 1 2 3 4 and M 3 doing 5 6 or M 4 doing 1 2 3 and M 3 doing 4 5 6; so, we will have to look at all of these when we start creating product based cells. So, let us look at the next one, which is considering a cycle time restriction.

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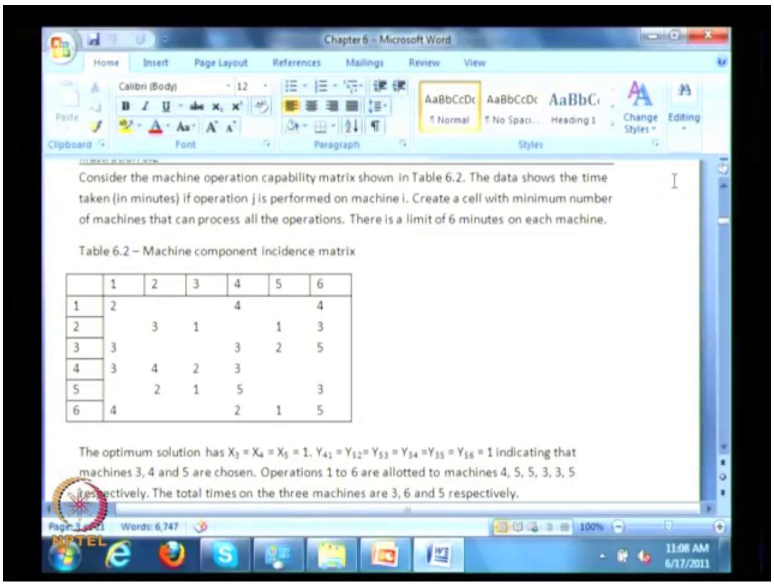

Consider the machine operation capability matrix shown in Table 6.2. The data shows the time taken (in minutes) if operation j is performed on machine i. Create a cell with minimum number of machines that can process all the operations. There is a limit of 6 minutes on each machine.

Table 6.2 – Machine component incidence matrix

	1	2	3	4	5	6
1	2			4		4
2		3	1		1	3
3	3			3	2	5
4	3	4	2	3		
5		2	1	5		3
6	4			2	1	5

The optimum solution has $X_3 = X_4 = X_5 = 1$. $Y_{41} = Y_{52} = Y_{53} = Y_{34} = Y_{35} = Y_{56} = 1$ indicating that machines 3, 4 and 5 are chosen. Operations 1 to 6 are allotted to machines 4, 5, 5, 3, 3, 5 respectively. The total times on the three machines are 3, 6 and 5 respectively.

So, this is our incidence matrix which has cycle times. So, when we do a cycle time restriction the formulation changes.

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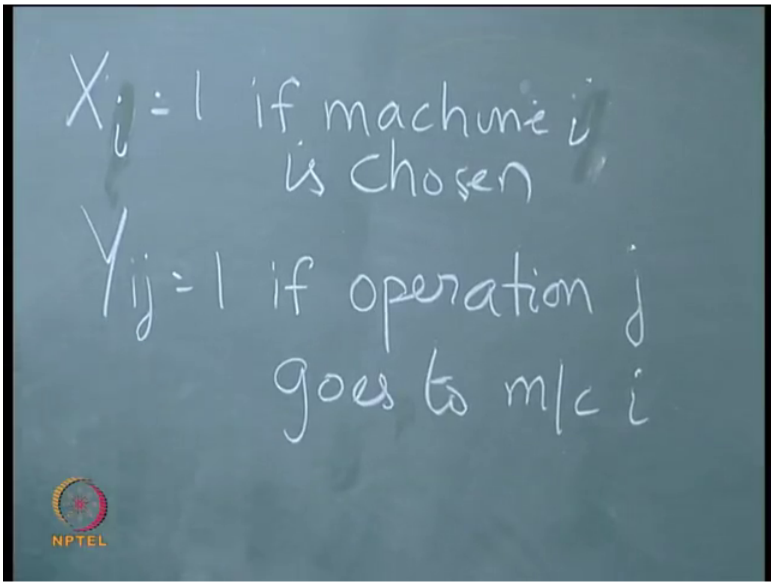

So, the formulation will become X j equal to 1 if machine j is chosen and Y or X i equal to 1 if machine i is chosen and Y i j equal to 1 if operation j goes to machine i. So, we have more variables that come in, and we if we have a cycle time restriction then we have to try and restrict the cycle time on each of these chosen machines and so on.

So, we will look at this formulation and subsequent formulations involving processing time cycle time cost and unidirectional flow in the subsequent lectures.