Manufacturing Systems Management
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Lecture - 04
Cellular Manufacturing Applications, Production Flow Analysis

In today's lecture, we continue the discussion on Cellular Manufacturing. We look at some applications of Cellular Manufacturing and address a few other relevant issues and then we move to describing production flow analysis which is a popular method to create Manufacturing Cells and part families.

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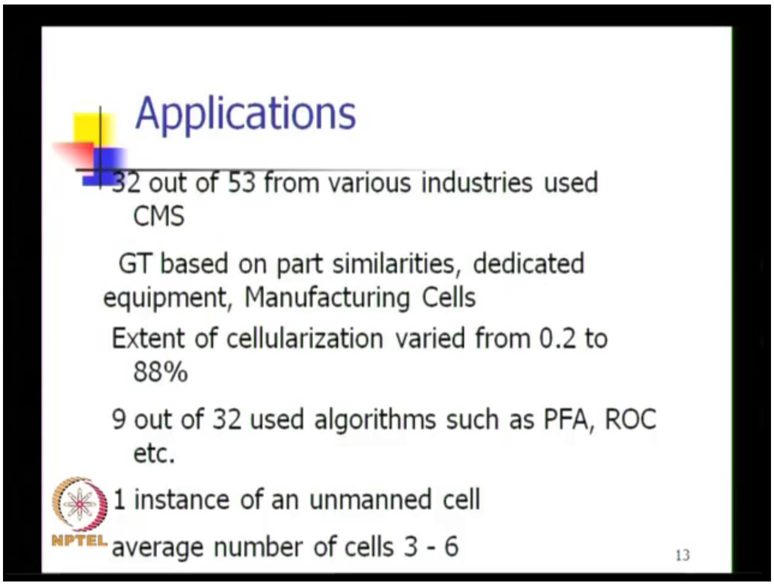

In the previous lecture, we started this slide on applications of Group Technology and Cellular Manufacturing. This data comes from a research paper written by higher and in 1987 where they surveyed 53 companies belonging to various industries and checked and verified whether they were using ideas from Group Technology and Cellular Manufacturing. So, as early as 1987, a survey indicated that 32 out of the 53 companies that participated in the survey indicated that they were using principles from group technology and Cellular Manufacturing and that they had Manufacturing Cells which made some components and parts. Then, asked how do they create the cells the answers indicated that cells were created based on part similarities and in some instances dedicated equipment were given to cells to manufacture all the parts and that was how the Manufacturing Cells were created.

The survey also observed that the extent of cellularization varied from 0.2 percent to 88 percent. The extent of cellularization is a figure which talks about the percentage of business in terms of money value which comes out from parts components made from Manufacturing Cells and that ranged from as small a value as 0.2 percent to as large a value as 88 percent. The large value of 88 percent indicates that the particular company had many existing Manufacturing Cells and had almost converted the existing functional system to a cellular system.

A company that has as small a value as 0.2 percent of business coming out of parts and components made out of cells indicates that they would have just begun the process of converting into Cellular Manufacturing and perhaps they might be having 1 or 2 pilot cells which were on trial or which had just been implemented.

Now, the other question or point of interest was where some of these Manufacturing Cells created using popular methods and algorithms. The answer was 9 out of the 32 applications said that they had used algorithms and these algorithms included PFA - Production Flow Analysis, ROC - Rank Order Clustering and so on. Now we will be looking at these algorithms in this course as we move along. There is also a report of one instance of an unmanned cell which means one company had implemented a cell that was completely automatic and did not have any human intervention. Some important pointers were that the average number of cells in a plant ranged from 3 to 6.

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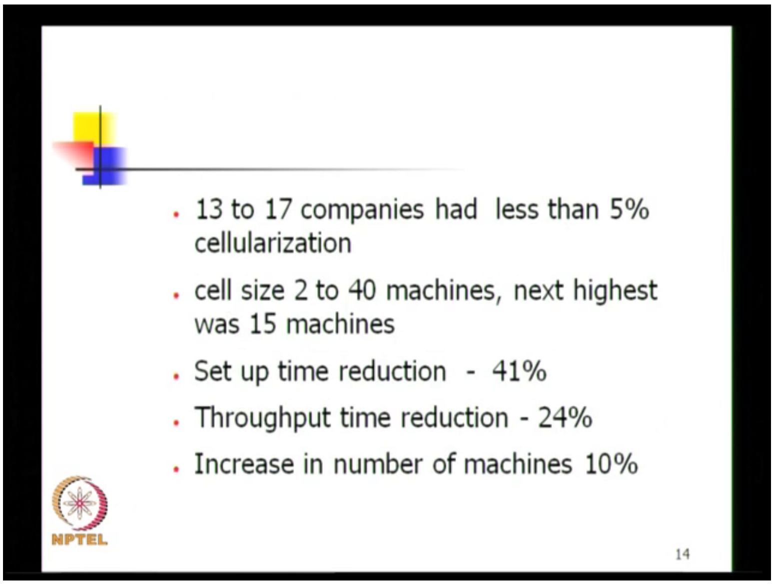

13 to 17 companies at that time had less than 5 percent cellularization which means 13 to 17 companies had just begun the process of implementing cellular manufacturing. Cell size varied from 2 machines to 40 machines the next highest was 15 machines in that case. Normally we do not have manufacturing cells with 40 machines. 40 machines is a very large number to be put inside one cell. So, 2 to 15 is a realistic number that one can think of and many times the number of machines in a cell averages between 8 and 10 or between 6 and 10 as the case may be. Other important gains that were reported by these companies where that set up times were reduced by 41 percent. Production time or time taken to produce or Throughput time was reduced by 24 percent while the number of machines went up by 10 percent. We have already seen that set up time reduction and total production time reduction are benefits from Cellular Manufacturing or Group Technology, but then this slide also tells us some kind of quantification or the extent to which companies have realized this benefit.

So, one could think in terms of up to 40 percent setup time reduction if one were to implement Group Technology or Cellular Manufacturing. As already mentioned the set up time reduction comes from the fact that parts that are produced in these cells are similar and therefore, would require less change over time on the machines therefore, set up time or change over time comes down considerably when Cellular Manufacturing is implemented. As already mentioned time taken to produce comes down because setup times reduce, waiting time reduces because smaller batch sizes are made time to transport material from one place to another reduces. Issues related to quality are better and therefore rejects and rework also gets reduced and therefore, there is a reduction in the overall time taken to produce as was also mentioned the number of machines can go up.

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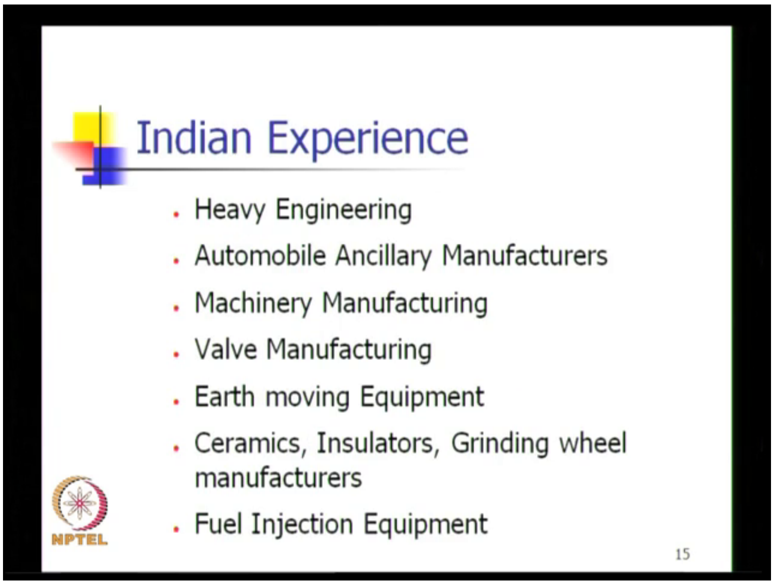

Now, having seen a little bit about results of a survey conducted in the United States of America in 1987. Let us now move towards the Indian experience where I have listed a set of companies or companies that make these kinds of products which have implemented Cellular Manufacturing. This list is only indicative it is not exhaustive. As we move along we would realize that more and more companies belonging to different industries have also implemented Cellular Manufacturing. These examples include companies that make Heavy Engineering products, companies that make Automobile Ancillary, Machinery Manufacturing, Valves, Earth moving Equipment, Ceramics, Insulators, Grinding wheel manufacturers, Fuel Injection Equipment manufacturers and so on.

But, if you look at what is happening in the manufacturing sector in India today, a very large number of companies belonging to almost all types of industry use similar manufacturing Group Technology. The only industry where you could not use it directly by separately creating manufacturing cells is the process industry. So, in almost all the discrete manufacturing types of companies there is an enormous potential to use Cellular Manufacturing.

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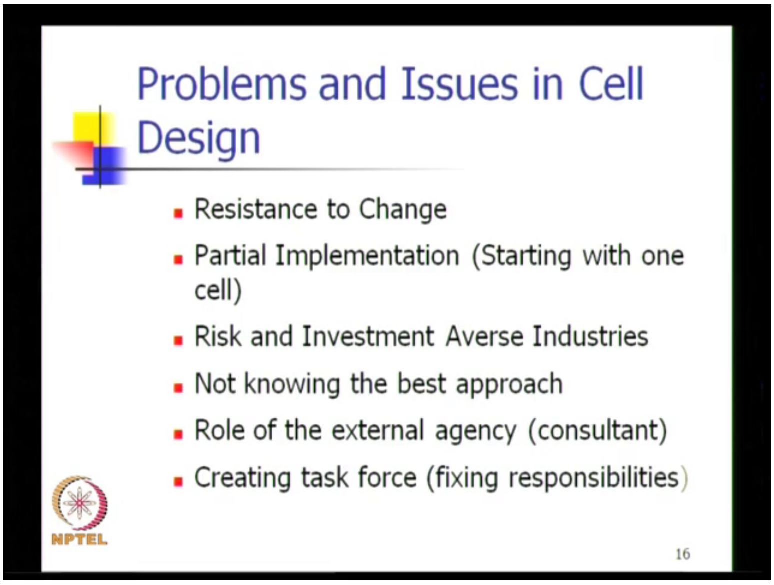

Now, what are the other issues when an organization moves or converts to Cellular Manufacturing? The first one that happens with any change technique or change management initiative is Resistance to Change. People are always used to the way things function and people are hesitant and reluctant to make changes. So, the first thing that every company has to do is to overcome this Resistance to Change. Most of the times this is done by educating people within the organization, the potential benefits of the use of this technique, indicating to them how similar companies or may be sometimes competitors have gained by using this technique also by telling them the advantage of the benefits as well as the possibility of growth that could come through the implementation of these techniques.

The other issue that organizations have to be aware of is Partial Implementation. Many times these change management techniques or these philosophies when implemented partly give rise to less than part benefit. Whereas, been implemented fully will give full benefit. Therefore, companies have to be aware that it when they start the process of implementing cellular manufacturing they should implement it totally and fully and try to create as many manufacturing cells as possible within the factory.

Third of course, is a Risk and Investment Averse Industry? So, companies have to come and be aware of the fact that there is an investment, but many times it is not a risky investment particularly ascertaining from the gains that other organizations have made by implementing this technique.

Few other points would include not knowing the best approach. Sometimes we have seen companies do step by step implementation. Sometimes we see companies do a complete change or a total transformation to a cellular system. So, many times they would not know which one to use. Also when the machines are rearranged and Manufacturing Cells are created, it takes a lot of time to get used to the new system, it takes time to relocate the machines and during all these times production may suffer output may suffer. So that would cause a temporary concern now organizations have to learn to overcome that solve that issue and move along.

There are examples were companies that work 5 days a week, worked 5 days with the plan and on the sixth day they made some changes in the layout and this process happened over 2, 3 months and finally, the correct cellular layout was implemented and then the company started working at steady state with a total Cellular Manufacturing implementation. Sometimes not knowing the role of the external agencies because, many of these initiatives are also driven by consultants who work with organizations. Many of these initiatives are also driven with possibility of implementing other initiatives alongside.

For example, companies would implement Cellular Manufacturing and would also want to implement Just in Time principles as well as principles of TQM. So, the extent to which these are combined, the time spent on implementation of each one of them sequentially and parallely are all issues that need to be looked. At last, but not the least, there is a need to create a task force within the organization with specific objectives and these task force would work closely with the change agents both from inside and outside the organization and finally implement these issues.

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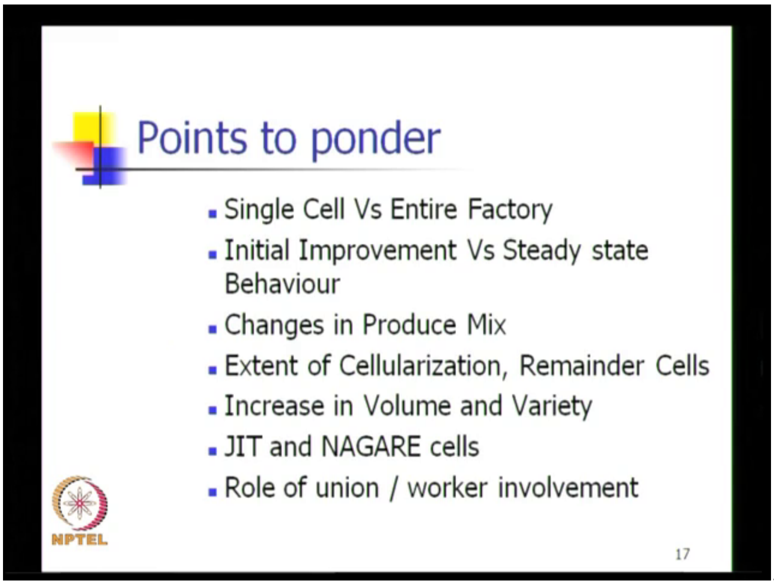

Few other points that we would look at before we move towards production flow analysis is, Single Cell Versus Entire Factory. This point I have highlighted earlier that many times companies would start with what is called a Single Cell or a pilot cell where they would look at a single product or a product that provides a large percentage of the business and then make a Manufacturing Cell exclusively for that product. And after depending on the success of that cell, would move towards creating more Manufacturing Cells and converting the entire factory into the cellular mode. What is important is, it is necessary to do both, it is necessary to start in a single cell or a pilot cell, but it is also important to very quickly undertake the task of converting the entire production system into a cellular system and not delay the change process. Delay in the change process will reduce the moral and the intensity of implementation and sometimes, the organization may not be able to achieve full benefits in time.

The second point is Initial Improvement versus Steady State Behavior. When the first cell or the pilot cell is created, the pilot cell produces at one particular product. Many times it is seen that the initial improvement will be very high which could sometimes create unnecessary expectation or very high expectation when the entire plant is converted to Cellular Manufacturing. For example, the pilot cell may give an additional 40 percent gain whereas, when the entire plant is converted one would get only about 20 percent gain in the production time. So, we should be aware of the fact that when the entire system is converted the actual gain may come down compared to a partial implementation. There would also be times when during a partial implementation one might get a feeling that the performance is actually not as much as expected. In either case the organization has to be patient and believe that when properly implemented Cellular Manufacturing would help achieve objectives such as setup time reduction, travel time reduction, production time reduction, better quality and so on.

One other important aspect is Change in Product Mix. Change in Product Mix is also closely related to the; another point which is in this slide which talks about increase in volume and variety. So, increase in variety would mean change in product mix.

Now, we will be looking at several aspects of another manufacturing in the lectures to come. At the same time, let me start by saying Cellular Manufacturing is a way by which the advantages of a line layout or a continuous production system are brought into a batch production system. Therefore, Cellular Manufacturing or Manufacturing Cells are very good when the volume is slightly higher and the variety is slightly lower. Increasing the variety or bringing a new product or part into a cell can sometimes result in addition of machines and change in the configuration of the cell. So, increase in variety is usually not handled or has to be handled extremely well in the context of CMS. Organizations will have new products different products as time progresses and manufacturing cells will have to be redesigned either temporarily or permanently to meet Changes in Volume and Variety.

It is an important aspect that one has to look at. One should also remember that these Manufacturing Cells have some kind of a lifetime. A cell for example, could work well under the conditions for about 3 years or 2 to 3 years. After which depending on the volume and variety or depending on the product mix, one more exercise of redoing the manufacturing cells or recreating the manufacturing cells. This exercise has to be carried out to handle changes in product mix.

Now, Extent of Cellularization and use of Remainder Cells is another issue. As we bring more and more products into the cellular mode of production the extent of cellularization will go up. At the same time they will they are aware of the fact that 100 percent would be very difficult because there would always be some common facilities which cannot be dedicated to individual cells. Many times facilities such as heat treatment, facilities such as a large press that takes care of certain operations, these things are still kept centralized and are not dedicated to different manufacturing cells. Therefore, it is almost difficult or impossible to get a hundred percent cellularization, but most organizations that have implemented it would report more than 90 percent cellularization.

The other aspect is the creation of Remainder Cells which was mentioned in the previous lecture, particularly when variety changes it would necessitate inclusion of new machines. As volume increases one can have a situation where we need more capacity on the machines which are in the existing cells. So when we need more capacity on the machines which are in the existing cells it is either required to buy another machine and put it in the cell or sometimes there will be a tendency to borrow capacity from some other cell. Now we know that borrowing capacity from some other cell would mean sending a part or a product from one cell to another which is not desirable. And therefore, Increase in Volume and Variety also would make it necessary to take a look at the capacity of the cells.

So, increase in volume and variety as well as changes in product mix are 2 important aspects. Sometimes this also leads us to creation of what are called Remainder Cells or service cells as I mentioned in the previous lecture where, a particular part would visit the assigned cell as well as the Remainder Cell or the service cell. So, creations of Remainder Cells become important as the product variety increases. There are 2 other aspects which are told here which is Just in Time and NAGARE cells. We will talk about just in time a little later in this course. We have already briefly described the NAGARE cells.

So, NAGARE cells are single operator manned cells which have automatic machines and which can give a large amount of output because of automation and being handled by a single operator. So, the extent of using NAGARE cells independently or NAGARE cells as a subset of other cells are also issues that one has to look at.

Last but not the least, sometimes we could have worker unions which also will have some ways of influencing the behavior and involvement of the workers. So, it is absolutely necessary that the operators and workers work in an environment where they cooperate and such an environment has to be created for the cell to be successful. Set of people who work within a particular cell should cooperate and should not belong to different groups or should not disagree with each other on issues. So, the human aspect of Cellular Manufacturing is also an extremely important aspect.

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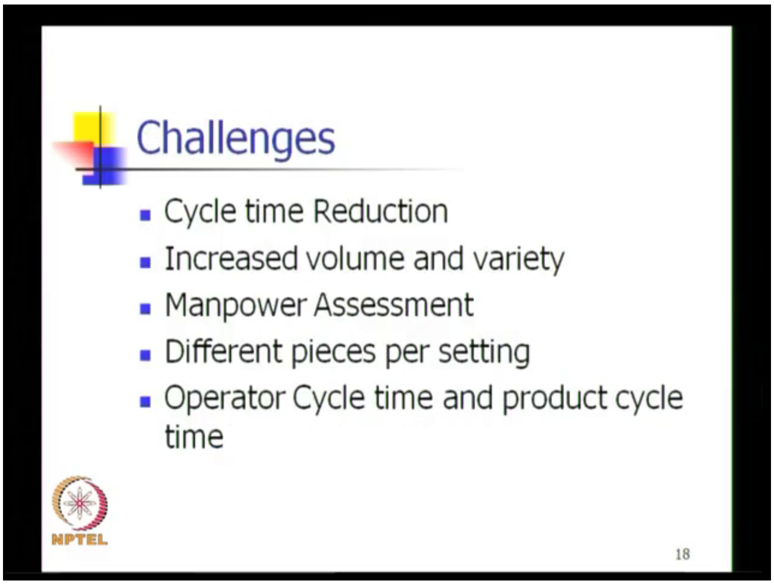

Now what are the challenges a few challenges are listed here. The perennial challenge is always to reduce the Cycle Time or time taken to produce. Implementation of Cellular Manufacturing would help us achieve this. So, time taken to produce comes down. But reducing the cycle time or time taken to produce is a continuous task which the organization always attempts to do. So, cellular manufacturing helps, but that is not the end. It does not achieve the Cycle time Reduction in totality once Cellular Manufacturing is implemented. In spite of implementing it organizations continue to work and try and reduce the cycle time. As already mentioned, Increased Volume and Variety is always a challenge to cope up. What would be the size of the cell, what would be the capacity of the cell and so on? That is another important aspect to look at.

Manpower Assessment, many times with the introduction of Cellular Manufacturing, the amount of people or the number of people required will reduce and that should not become an issue during the implementation of this technique. Organizations have to understand and carry out a manpower assessment, assign correct roles for the people and utilize other existing people in different roles or in defined roles.

Different pieces per setting is another interesting issue which we will see as we move along, but then what also happens is this. When we have automatic machines within a cell and if an operator handles more than one machine in the cell. Let us assume that a particular operator works on machines 1, 2 and 3 in a particular cell and let us assume that the operator first works on machine 1 then moves to machine number 2 and then to machine number 3 and comes back to machine number 1 and so on. We also assume that all 3 machines are automatic machines. So, when the operator is working on 2 and 3, the actual production is being done in machine 1 and when the operator is working on machine is loading and unloading on machine 2 and 3 production is done in machine 1 and so on. When the operator is loading and unloading on either 1 or 2 production is done in 3 and so on.

Now, if the number of pieces that go into the machine per setting is the same then the operator will visit machine number 1 once, machine number 2 once, machine number 3 once and go back to machine number 1 and so on. But for example, if machine number 1 can do 2 pieces at a time while machines 2 and 3 can do only 1 piece at a time, then for every single visit on machine 1 the operator has to visit machines 2 and 3 twice. So, these things can become issues and operator walking patterns need not be symmetric even though it will repeat. So, these things also will have to be looked at when particularly different types of machines are brought into the cell. Many times the cell will also contain a set of very new machines and some old machines. Newer machines give additional capability. So, newer machines would have you know twin tables and different ways of setting it up. Whereas, older machines will have a more will give lesser flexibility towards setting it up. So, one has to understand the number of pieces that go per setup on the machine and it is effect on the operator walking.

Also the operator cycle time and product cycle time match is extremely important. Because the success of using automatic machines because of which a single operator handles multiple machines comes from the idea of matching the operator cycle time and the product cycle time. So, I had mentioned that when the actual operation is happening in machine number 1 the operator would be loading and unloading on some other machine. So, when the operator completes the loading unloading cycle and returns to that first machine by that time the operation on the machine should be over and the piece should be ready to come out.

So, neither the machine should be idle at that point waiting for the operator nor should operator be idle waiting for the machine. Sometimes we could allow operator idleness for a few seconds and so on. But one has to match the operation time with the operators loading and unloading time as the implement NAGARE cells or we implement cells with multiple operators handling different types of machines in the cell. So, these are some of the points that one has to look at.

Now, with this we move towards Production Flow Analysis. Now we have seen; what is Cellular Manufacturing and; what is the basic idea in Cellular Manufacturing, what are the various issues. We have also seen some aspects of implementation of Cellular Manufacturing, some examples of types of companies, some results from surveys and we have also seen some issues and challenges related to Cellular Manufacturing. Now let us spend some time on answering this question; how do I create these Manufacturing Cells. Before I get into that let me also take you through to this particular slide that we have seen.

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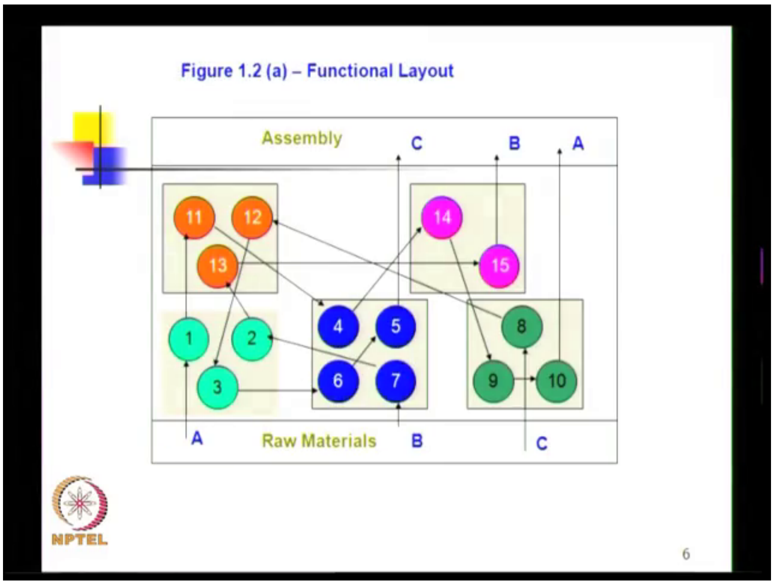

We have seen this slide which represents a functional layout and we have seen this slide which represents the cellular layout.

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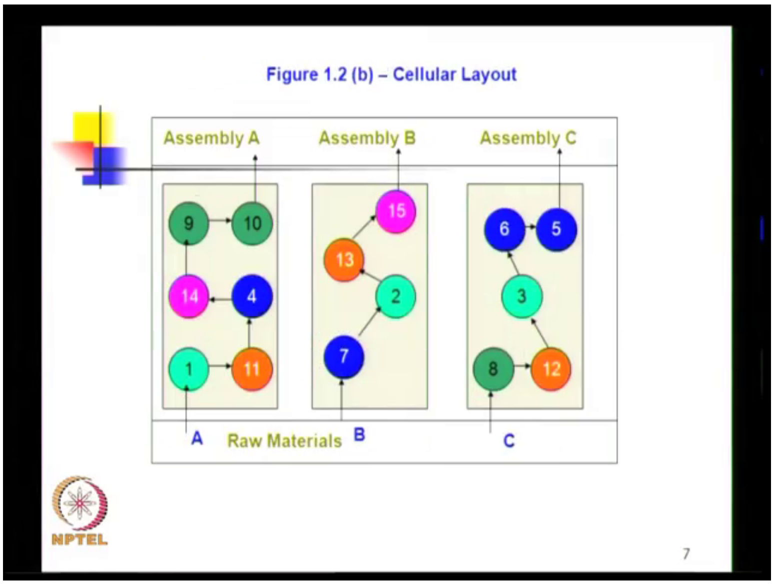

Now, as I described this is a schematic diagram of a functional layout. This is a schematic diagram of a cellular layout. Now when we look at this slide where machines are grouped according to functions and when we look at this where the machines are arranged depending on the requirement of A, B and C. One might get a feeling that making these cells is a relatively simple process. But actually making these cells or creating these cells is a little more involved even though many common sense based approaches can be used to create these cells.

So, now we move towards a method called Production Flow Analysis which we briefly described which we will now get into how we use this Production Flow Analysis to create machine cells and associated part families. And as I mentioned production flow analysis is a method that was first created by Burbidge. Burbidge was one of the early pioneers in group technology and cellular manufacturing who researched extensively, published extensively and also wrote about a lot of practical aspects of Cellular Manufacturing and Group Technology. He used the term Group Technology more than in Cellular Manufacturing and he formulated this method called Production Flow Analysis.

Now Production Flow Analysis can be carried out in multiple forms and the form that we are going to see is called a manual method of Production Flow Analysis. Now in this method we are going to see how we can reorganize an existing system into a cellular system. We are not seeing how we create a Cellular Manufacturing system from scratch. What we assume is that there is an existing functional layout and how we distribute the existing machines and create a cellular layout from the functional layout. So, there is an existing factory with machines and parts.

Now, Production Flow Analysis is in total carried out in 3 phases. One is called factory flow analysis, one is called group analysis and the third is called line analysis. So, factory flow analysis, group analysis and line analysis. Factory flow analysis is the concept in which a large company that has factories in many places decides which are the products that have to be made in which factories. So, depending on the product allocation machinery is bought and factories are created. Now what we are going to see is the second one called group analysis which means given a factory which means given a set of machines that are available and a set of parts or components that are being made; how do we create manufacturing cells.

The third one called line analysis is about after creating these manufacturing cells how do we address further issues such as capacity of the cell, layout of the cell, flow within a cell, sequencing and scheduling within a cell and so on. So, we will address group analysis which is the second part where given a set of machines and components we will try and create manufacturing cells.

Now we start Production Flow Analysis by looking at an example.

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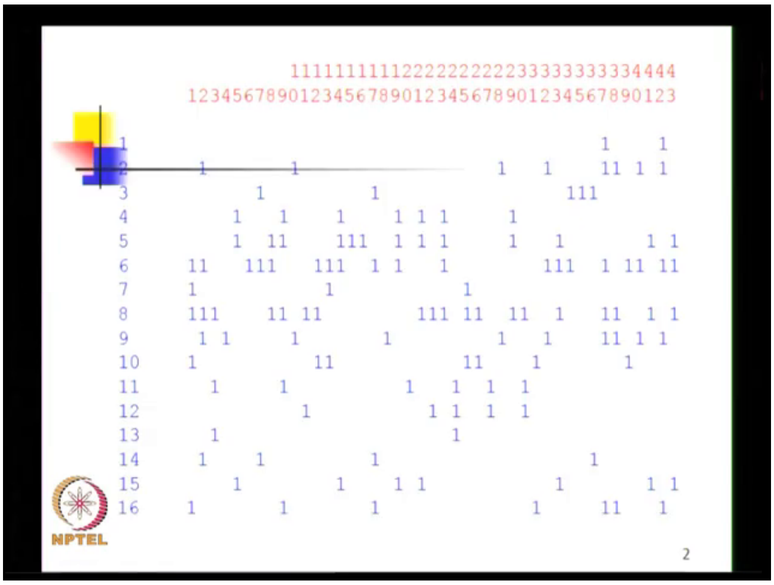

And this is the example that we will be using to explain Production Flow Analysis. Now in this example you see a matrix of ones and zeroes. This matrix has 16 rows which are given as 1 to 16 here. It has 43 columns where the column numbers are written here. For example, you can see column number 10 written as 1 and 0 and column number 43 written as 4 and 3. Now this matrix is called a machine component incidence matrix. And we have made a mention about the machine component incidence matrix in an earlier lecture.

Now this matrix is has been used by many researchers and has been extensively used in the Group Technology Cellular Manufacturing literature. And this matrix was first used by Burbidge to explain a few things in his research paper and much later it has been used by King in his paper which discussed the Rank Order Clustering. And several other authors and researchers have used this matrix to explain many algorithms. So, we would also use this matrix by giving adequate reference to literature to explain how Production Flow Analysis can be carried out to create Manufacturing Cells and part families.

Now this matrix or the data in this matrix represents the visit or incidence of 43 parts on 16 machines. Now this is a 0, 1 matrix where the entries are either 1 or 0. The ones are shown here and the zeroes are not shown explicitly. The zeroes are shown as blanks or blank spaces. So, when we use the word blank it means that there is a 0 in that position and it also means that this particular part or component does not visit this particular machine. So, to explain this matrix further if we look at this particular entry with which there is a 1. This 1 represents an entry in row number 1 and column number 37. It means that part number 37 visits machine number 1. Part number 42 visits machine number 1. Part number 1 does not visit machine number 1 because there is a blank or there is a 0. So, that is how this matrix is created.

Now, very early research in Cellular Manufacturing suggested different ways of creating the machine component incidence data or machine component incidence matrix. In one of the early work Burbidge explains a way by which this data can be captured or created. We will see that and then we would see how capturing this data essentially became transforming it into a 0, 1 matrix.

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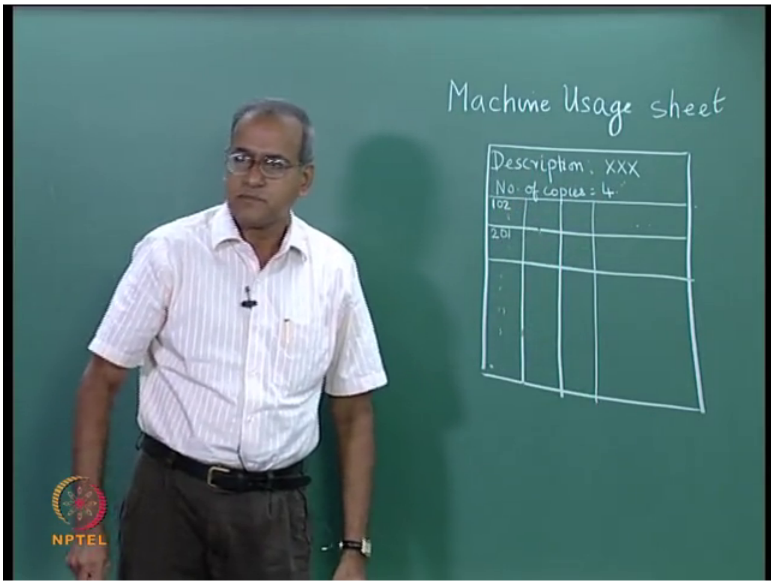

So, in very early research Burbidge suggested something called a machine usage sheet. Where he suggested having a particular sheet for every machine, where the description of the machine is written in this sheet as well as number of identical copies of the machine. For example, a particular type of machine one could have 4 in number in that factory. So, that is written as number of copies of that machine and then the machine usage sheet can be divided now into 10 rows and 10 columns. So, you can assume that there are 100 spaces 10 rows and 10 columns. Now every part that moves in the factory has a certain route card and the route card information tells us the set of machines that this part is actually visiting.

So, by looking at the route card now for example, if a particular part requires this particular machine, let us say this machine is called xxx and let us say if part number 102 requires then we would write part number 102, part number 20, like that, as we see from the route card if this machine is required by the various parts, the part numbers are written here. So, that at the end of it once we exhaust it the information from all the parts that are made in this factory the machine usage sheets would tell us how many parts are visiting each of these machines from which the machine component incidence matrix can be created.

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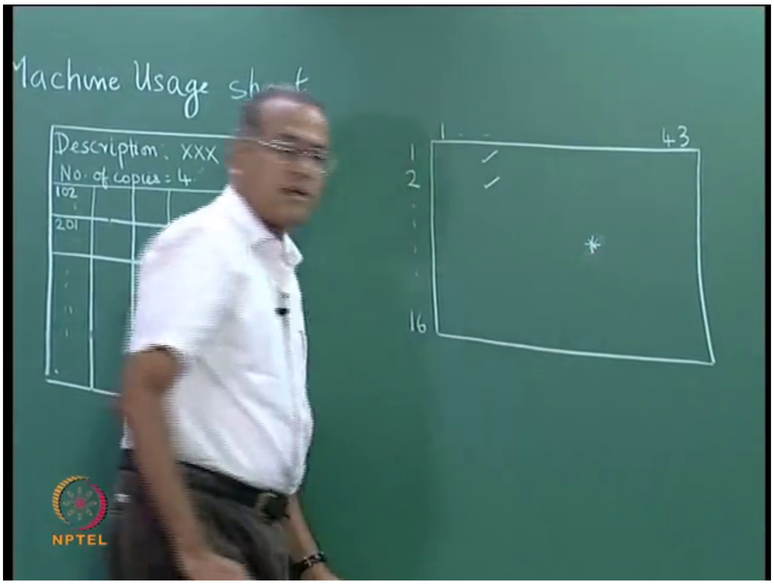

Now, there are also times when the machine component incidence matrix was not a 0, 1 matrix, but it was more. For example, if we have this machine component matrix with 16 machines and 43 parts. Sometimes it was created by using either tick marks which indicated that this particular component visited this particular machine. Or researchers even used star marks or any other indicator to show that the particular component visited a particular machine and after a while it was accepted and people started using zeroes and ones to show that 1 represents the visit of a machine and 0 represents that the part or component does not visit that machine.

So, it actually takes a certain amount of time and effort to create this initial machine component incidence matrix particularly from the route card information that exists in the plot. Because it is taken from the route card information this captures exactly how the current roots of various parts happen in the factory. There could be an alternate route which does not figure in this because this represents the current movement of parts within the factory. So, we need to be aware of that also. Though the first step after we create this or even before we move to the first we have to understand a few things that this matrix conveys and few things that this matrix does not convey.

Now the only thing that this matrix conveys is the incident data which means whether a particular part visits a particular machine or not. It also tells us how many parts are being considered which is 43 in this example and how many machine types are being considered.

Now I am using a word called machine type instead of machine. Now in this case there are 16 machine types. Each machine type is unique, is a row and each machine type can have more than 1 copy of that machine.

So, when we use the word machine with respect to this, we consider a machine type and we are aware that multiple copies of that machine type can exist in the shock floor. So, there are 16 machines which means there are 16 machine types, but if we also include multiple copies that may be available, we will actually have more than 16 machines actually on the shock floor. What it does not convey, it does not convey many things. It does not convey the volume of production, it does not tell us how many in number of this part is made, it does not convey the processing time taken by the part on that machine, it does not convey the order or sequence in which these machines are visited.

For example, if we take part number 1 this would tell us that part number 1 visit 6, 7, 8, 10 and 16. It visits these machines. It does not tell us in what order it is visiting these 5 machines. It need not be 6 followed by 7 followed by 8 followed by 10 followed by 16. It could visit in a different order. So, the volume of production or the quantity of production, the times taken to manufacture, the order or sequence of visit on the machines are all not captured by this matrix. So, in spite of the fact that this matrix does not carry a lot of information, it is still extremely useful for us to create machine cells and part families. We will see how we do that.

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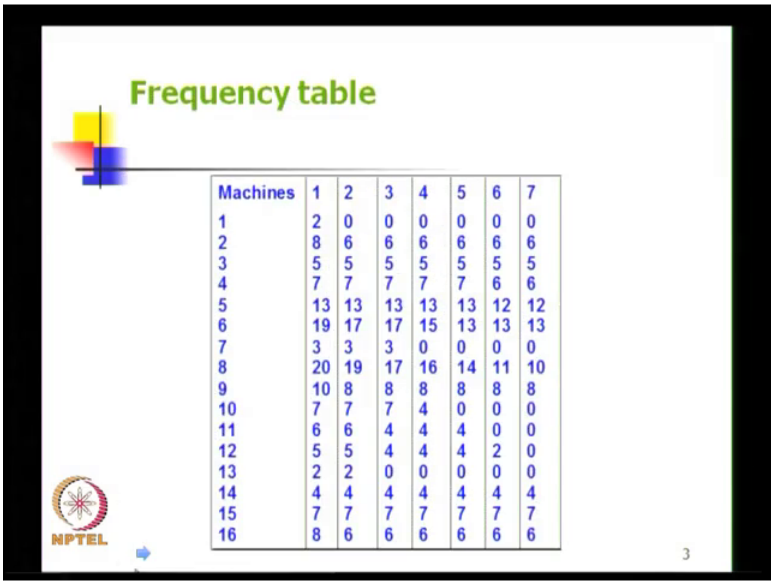

Machines	1	2	3	4	5	6	7
1	2	0	0	0	0	0	0
2	8	6	6	6	6	6	6
3	5	5	5	5	5	5	5
4	7	7	7	7	7	6	6
5	13	13	13	13	13	12	12
6	19	17	17	15	13	13	13
7	3	3	3	0	0	0	0
8	20	19	17	16	14	11	10
9	10	8	8	8	8	8	8
10	7	7	7	4	0	0	0
11	6	6	4	4	4	0	0
12	5	5	4	4	4	2	0
13	2	2	0	0	0	0	0
14	4	4	4	4	4	4	4
15	7	7	7	7	7	7	7
16	8	6	6	6	6	6	6

Now, the next thing we do is to create this thing called a frequency table. Now the frequency table represents a table for each of the 16 machines. So we can write 1, 2, 3, 4 up to 16 here. Now let us go back to the earlier matrix and look at machine number 1. How many parts require machine number 1. 2 parts require machine number 1. For some of the 1's in a row will tell us the frequency of visit or the number of parts that are visiting that particular machine. So, for machine number 1 it is 2. For machine number 2 it is 1, 2, 3, 4, 5, 6, 7, 8 and so on. So, the first column of the frequency which is this particular column. This particular column just shows the number of parts that are visiting each machine and it is simply a row sum. So, 2, 8, 5, 7 etcetera are all here.

Now let us see the rest of the columns will be created later as we move along and I will explain. So, right now we have seen how this column is created and how this column is created. Now once we create this column, look at this column which is called column number 1 and find out that machine which has the smallest frequency. So that machine which uses minimum or on which minimum number of parts are incident. So, we now realize from this that machine number 1 and machine number 13 are the machines that have the smallest frequency of 2 parts visiting them. Now, you can take either machine number 1 or you can take machine number 13 to begin with. So, we take machine number 1 to begin with. So, what we do now is, we now go back and create a small sheet with machine number 1 being the machine chosen based on smallest frequency.

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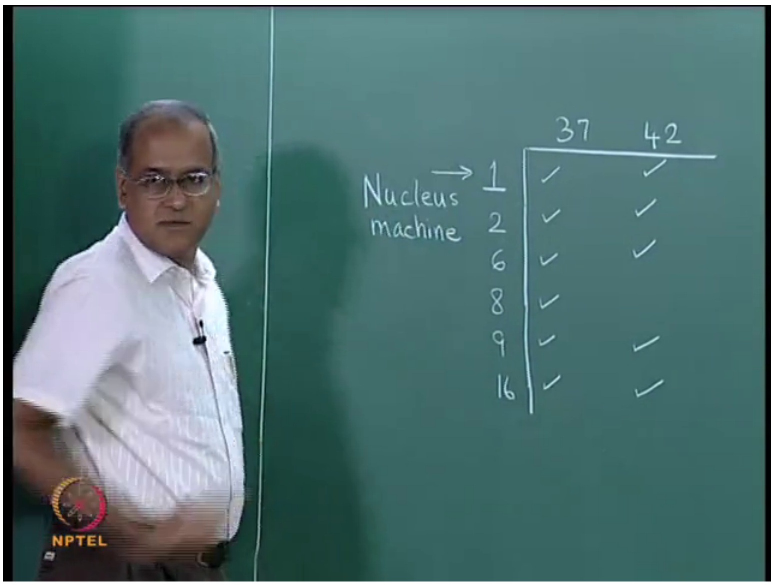

So now we go back to this table and look at the row corresponding to machine number 1 and you realize that the 2 parts that are there that we have seen are part number 37 and part number 42. So, we write part number 37 and part number 42 here, as the 2 parts with the frequency. We also go back to this matrix again and look at column number 37 and column number 42 which correspond to the part numbers 37 and 42 and go back and see; what are the other machines that they visit. So if you look at column number 37 it is 1, 2, 6, 8, 9 and 16. So write 1, 2, 6, 8, 9 and 16, which are the machines that 37 visits and put either a tick mark or a star mark to indicate that this visits all these machines. Now, go back to 42 and see; what are the machines that 42 visit. 1, 2, 6, 9, 16. And now go back to this and say 1, 2, 6, 9 and 16.

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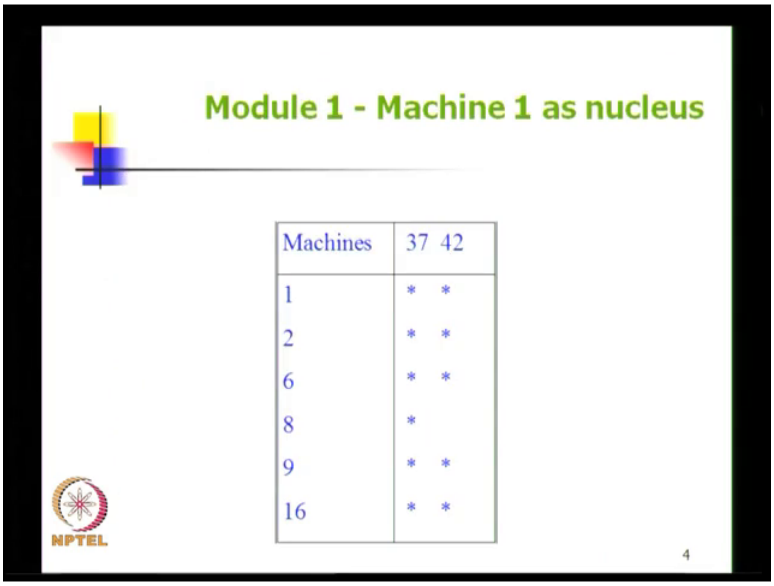

Now, this is shown in this matrix except that the tick marks that we drew are replaced by star marks. So now, we have created something called the first module. Now the first module that we have created has part numbers 37 and 42 and machines 1, 2, 6, 8, 9 and 16. While there are some simple rules that we have followed. The first module is created out of a machine which has the smallest frequency, which is machine number 1 and this machine with the smallest frequency from which we created is called a Nucleus Machine which is written first. So, the Nucleus Machine is written first. The frequency of the Nucleus Machine gives us the number of parts that we are going to have here. So, the 2 gave us 37 and 42 and then we wrote all other machines that are required by this 37 and 42 and we wrote this.

Now, what we have essentially done is we have said that if we take component numbers 37 and 42 together and we create a cell with machines 1, 2, 6, 8, 9 and 16. Now we can completely or entirely manufacture 37 and 42 within this particular cell containing these 6 machines. So, we have just created 1 module. This is not final. These modules will be modified again they are only partly through the algorithm. So, we create 1 module with machines 1, 2, 6, 8, 9 and 16 and with components 37 and 42.

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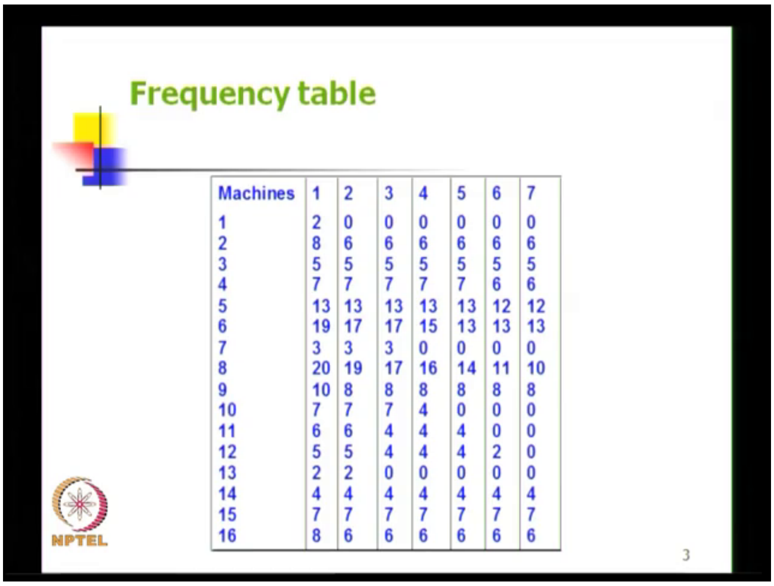

Machines	1	2	3	4	5	6	7
1	2	0	0	0	0	0	0
2	8	6	6	6	6	6	6
3	5	5	5	5	5	5	5
4	7	7	7	7	7	6	6
5	13	13	13	13	13	12	12
6	19	17	17	15	13	13	13
7	3	3	3	0	0	0	0
8	20	19	17	16	14	11	10
9	10	8	8	8	8	8	8
10	7	7	7	4	0	0	0
11	6	6	4	4	4	0	0
12	5	5	4	4	4	2	0
13	2	2	0	0	0	0	0
14	4	4	4	4	4	4	4
15	7	7	7	7	7	7	7
16	8	6	6	6	6	6	6

Now, we go back to this frequency table and now we look at this column number 2. Till now we have to assume that we have seen up to column number 1. So, we are now going to create this column number 2 using this. Now in this table machine number 1 has 2 frequencies, 2 stars. So, 2 minus 2 becomes 0. In this table machine number 2 has 2 stars. 8 become 6. In this table machine number 3 does not exist therefore, in this column 5 remains as 5. In this table machine number 8 has only 1 star and therefore, in this table machine number 8 has 19. So, like this column number 2 can be created from column number 1 by adjusting the frequencies of already created modules.

So now, we look at column number 2 and then we try and find out a Nucleus Machine or a machine that has the lowest frequency. Now when we start doing this you realize that machine number 1 has 0 and therefore, it will have the lowest frequency. Therefore, we will now identify a machine which has the lowest nonzero frequency. Now we realize that this 13 with frequency of 2 is the lowest nonzero frequency and we create another module with 13 as the nucleus machine and we proceed. And we will see the remaining part of this algorithm in the next lecture.