Manufacturing Systems Management
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Lecture- 03
Introduction to Cellular Manufacturing

In this lecture we study cellular manufacturing in detail. We have already introduced the idea of cellular manufacturing in the earlier lecture, as one of the ways by which manufacturing systems geared up to meet the requirements. So, cellular manufacturing also called group technology. These 2 terms are used interchangeably. Even though we will see some of the differences as we move along, most of the situations these 2 terms are used interchangeably. So, group technology are cellular manufacturing.

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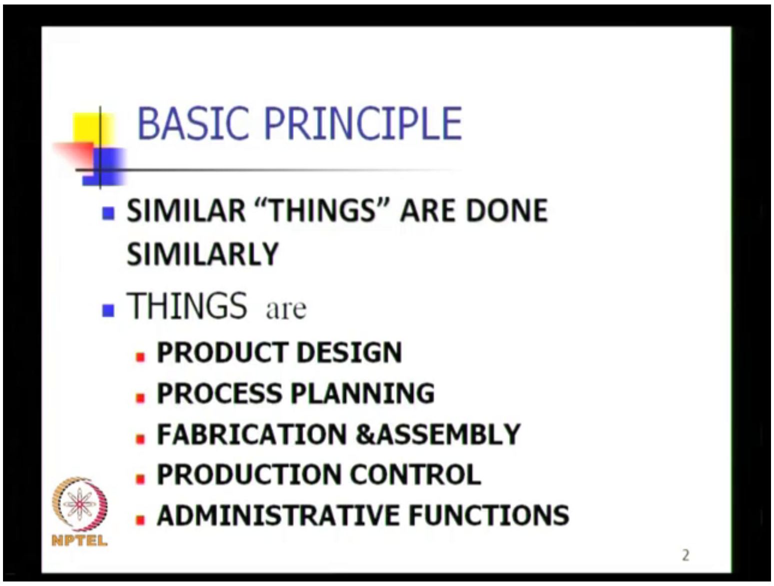

The basic principle in this is that similar things are done similarly, or similar things are done together. Large systems are made into smaller sub sets. And therefore, they can be handled easily and the processes become simple.

So, the similar things can be product design, process, planning, fabrication, assembly systems, production control, mechanisms and other administrative functions. All of these can be done in a simple manner with the introduction of group technology or cellular manufacturing. The most important thing in group technology is to divide the manufacturing facility or manufacturing system into small groups or cells of machines, and when we consider cells of machines it is called cellular manufacturing. So, in addition to dividing the machines into cells, we also divide the parts that are made in the manufacturing system into families which are called part families. Once again, we use the word part and component interchangeably; they mean the same in the context of cellular manufacturing. So, machines are divided into machine cells or grouped into machine cells parts are grouped into part families and part families are assigned to machine cells.

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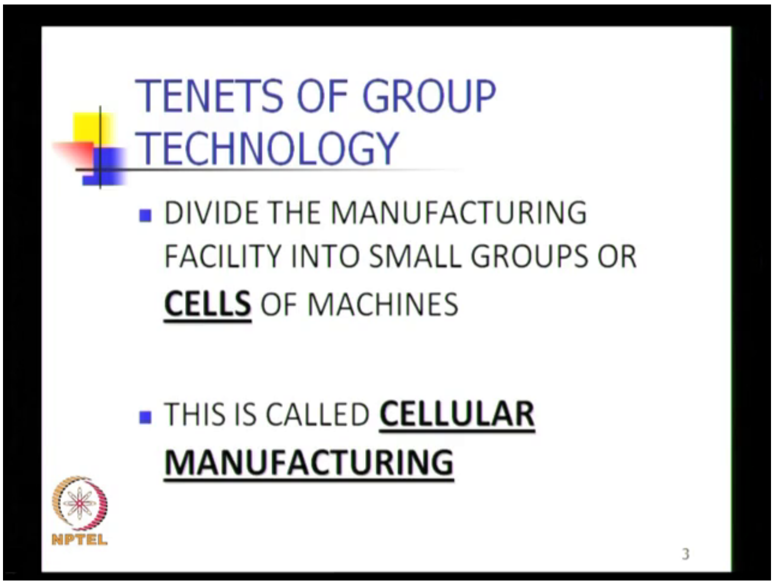

Once this is done we can imagine that we have what is called factory within the factory, and each manufacturing cell will act like an independent manufacturing facility.

So, it is like dividing a big factory into smaller factories, which are located within a factory. The size comes down and therefore, control becomes a lot easier.

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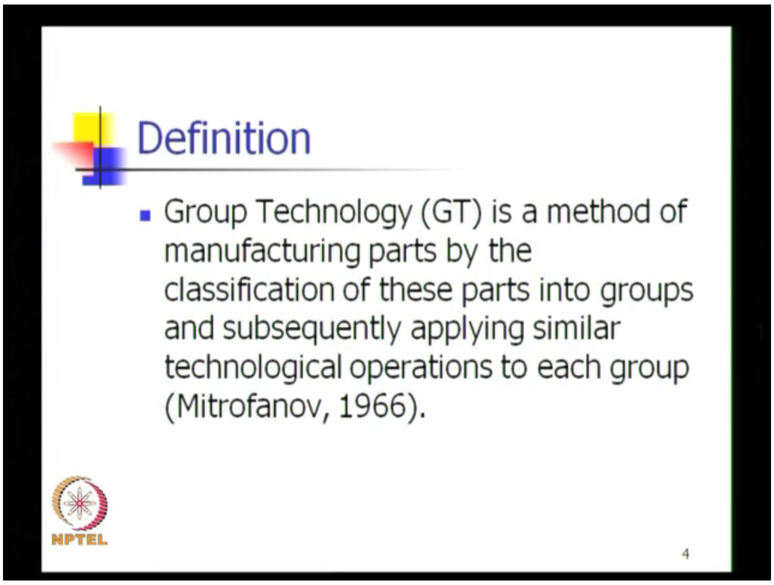

A very traditional definition is group technology is a method of manufacturing parts by classifying these parts into groups and subsequently applying similar technological operations to each group. So, this definition is given by mitrofanov. In 1966 mitrofanov is a very famous person who has worked in group technology and some other manufacturing. And he has also written one of the early books in this field. So, this definition, once again talks about the same thing that we group the parts into part families and then create machines cells for the part families. Another way of looking at it is to group the machines and create machine cells also create part families. And then attach each part family to a machine cell. So, in cellular manufacturing machines are grouped into cells and parts are grouped into families such that all the parts within the family are completely manufactured by the assigned cell.

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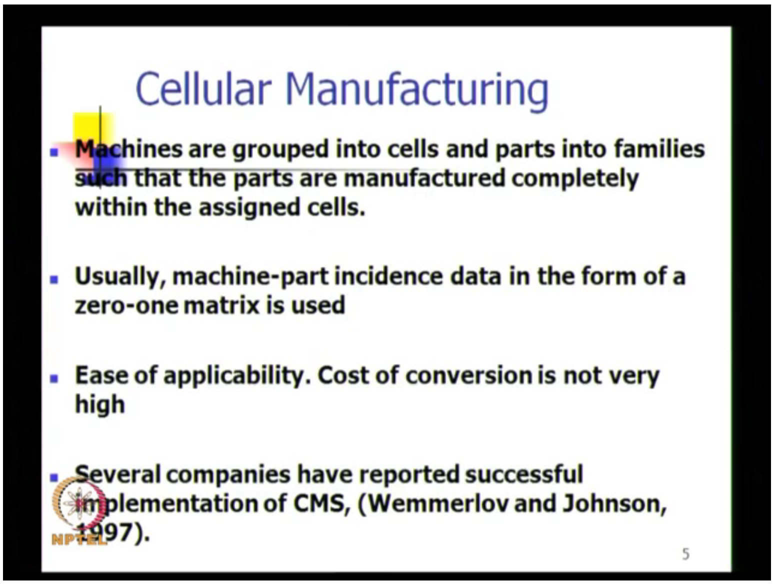

So, the machines are grouped into cells parts are grouped into families. And once a part family is assigned to a machine cell, the machine cells are created in such a manner that all the machines require to make every part in the part family is available in the machine cell. So, the challenge is to create these machine cells, such that these machine cells are independent. All the machines require to make each and every part in the part family is available in the machine cell, and the machine cells have enough capacity to meet the volume of production.

So, the biggest challenge or the first challenge is to create these machine cells and part families. And if we look at literature as to how researchers and practitioners have tried to create machine cells, and part families the data is usually captured in the form of a 0 1 matrix, which we will see as we move along in this course. So, the machine part incidence data is captured, machine part incidence data means that; the incidence or the visit of parts on the machines is captured in the form of a 0 1 matrix. That is, if the manufacturing system has about say 20 machines and makes 50 parts, then we will have A 20 by 50 matrix, where each of the 20 rows will represent the 20 machines, the 50 columns will represent the 50 parts. And if a particular part visits a machine then there is A 1 which captures the incidence of the visit of the part on the machine. If the part does not visit a machine then there is a 0.

So, the visit of parts on the machines is captured in the form of a 0 1 matrix, which is called machine part incidence matrix or machine component incidence matrix. So, we will be using these matrices to do some computations to create machine cells. As we move along cellular manufacturing, has also been applied extensively in practice largely due to 2 important reasons. One is the ease of applicability it is a very simple technique it does not involve very complicated formula or equations or methods application is very simple and a lot of common sense going into it. So, due to ease of applicability it has been applied extensively.

Secondly, more importantly the cost of conversion is not very high. So, if one wishes to convert a functional layout for batch manufacturing into a cellular layout or a group technology-based layout. The cost of conversion is also not very high there is a cost of conversion. Sometimes it may be required to buy some additional machines. So, there is an additional cost of conversion, but it is not a very costly proposition to convert it is easy to do cost is not very high.

And ordinarily time taken to convert is also not very high, and that would depend on the way the conversion takes place. Also, several companies have reported successful implementation of cellular manufacturing, there is a reference to this paper by wemmerlov and Johnson which appeared in 1997 which surveyed successful implementation of group technology or cellular manufacturing, where they have reported several instances of successful implementation particularly in the western countries and united states. In this lecture we will also see some examples of companies in India that have applied this technique. Now this is a schematic representation of a functional layout for batch manufacturing.

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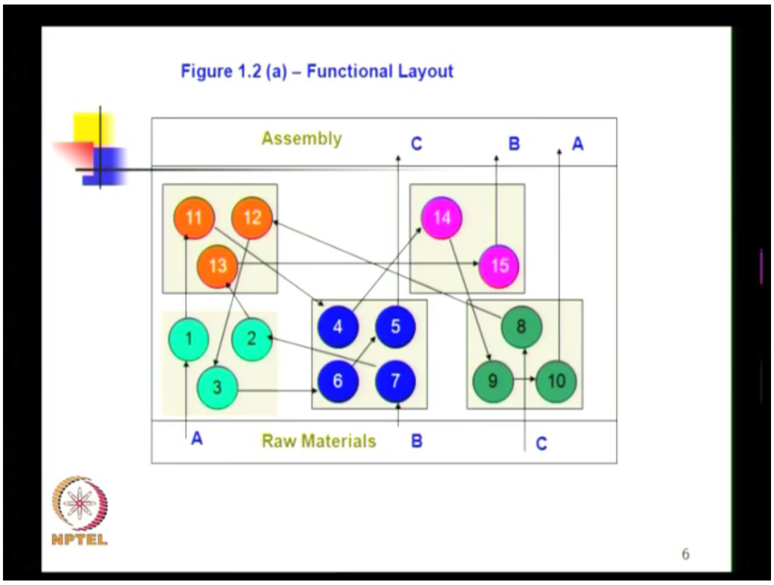

So, this captures a shop which has about 15 machines, and these 15 machines are grouped according to a functional layout or departmental specialization. So, we assume that machines 1 2 and 3 which are shown with some kind of a bluish green. They represent one type of machines, example it could be lathes. 4 5 6 and 7 which are shown in blue represent another type of machine. 8 9 and 10 which are shown in green represent a third type of machine, there are 3 machines here. 11 12 and 13 in orange represents another set of machines, and 14 15 in pink could represent another set of machines.

So, this layout is such that machines which are functionally similar, which means machines that can do the jobs interchangeably, because of functional similarity like 1 2 and 3 are grouped together, and they form a department. This is not cellular layout or group technology layout. This is a functional layout, where machines performing functions are grouped together. So, there are 5 departments. And we have shown A B and C which are 3 generic type of products. They could represent product families. So, a product family A or every product or part in family A would visit for example, one and then go to 11, then come to machine number 4, then go to machine number 14, then go to machine number 9, and then 10, and then would leave this system.

So, typically a component belonging to A would visit 1 11 4 14 9 10 and it would go out. Similarly, a part or component belonging to a group B or family B or a typical part B would start with 7 go to 2 go to 13 then go to 15 and then come out. Similarly, C would begin with 8 12 3 6 5 and it would come out. So, we have captured or shown how typically parts and components would move in a functional layout. First and foremost, the think that comes here is there are lots of arrows which indicate a lot of material movement and travel within the functional layout or amongst the departments in the functional layout. So, there is a lot of material movement and travel. Now each department is responsible for an operation or a set of operations. Here for example, 9 and 10, once again we have another example of 6 and 5 and so on.

So, as I mentioned in in an earlier lecture the each department here would be responsible for that particular operation or function and is not generally responsible for the overall production of A or B or C. So, the ownership and responsibility is for the process, and is not for the product. And it can happen that now in this particular example we have not shown 2 or 3 products or parts visiting machines one after another, but in large systems where we make about 50 to 100 parts or components inside a plant now we could have situations where each machine has a set of parts visiting, and if these parts are not very similar then the change over time or set of times are very high.

Now each one of these is responsible for a certain process and operation and the quality aspects are restricted to the process or operation. Sometimes we could have a quality control at the end of each operation in each department, but at the end of the day the quality is also towards the process and not towards the product. So, some of the limitations of the functional layout as was pointed out in an earlier lecture, some of these limitations are ownership is on the process and not on the product. There is a lot of material movement inside less control over the manufacturing operations less control over quality large change over times. And in systems like this when there is a lot of material movement from one department to another automatically production batch sizes will be large. Because one it the material the parts have to move from one department to another, it would be economical to have larger batches.

So, that the cost of transportation is brought down. Also if set up times or product change over times and set up times are high they would also indicate a large production batch quantity, if economic batch quantity formula are used to find out the batch quantity. So, parts and component would be made in large batches. And therefore, there will be lot of work in process inventory in these departments or within these departments. So, these are some of the disadvantages which increase cost as well as increase the time taken to make the final product. And if we look at this in the context of the requirements of manufacturing the price has to be brought down, a time to produce has to come down and inventories has to come down.

So, when people understood these limitations. Then they asked themselves, is it now possible to get the benefits of a line layout or a functional layout and apply it to batch manufacturing. So, with this idea cellular manufacturing was bought. But I have said I have repeated this I have said this before, but let me repeat it again, that there are some advantages of this that we have advantages of a set of similar machines which are capable of doing similar operations are grouped together.

Therefore, if for some reason one of the machine is not available. It is still possible to substitute it with another machine. And therefore, we can get the advantage of pooling similar resources, which is an advantage here. So, there is an advantage in utilization there is an advantage in quickly substituting one machine for another in case of a non-availability. But the disadvantages are increased cost and increased time and less ownership. The line layout are functional layout exactly has the opposite where whatever are the disadvantages in functional layout become the advantages in line layout and vice versa.

So, line layout it is always possible to have better quality, the less changeovers machines that are required to make the product are now located close to each other. Here machines that are required to make a are spread out. So, there is more control in a line lay out than in a functional layout in terms of control of the product. So now, practitioners and researchers thought can we apply some ideas from the line layout into batch manufacturing, and the cellular was born through this. Now let us go back and look at the same 15 machines this is again a schematic representation of cellular layout. So, if we look at part A. Part A would require 1 11 4 14 9 10.

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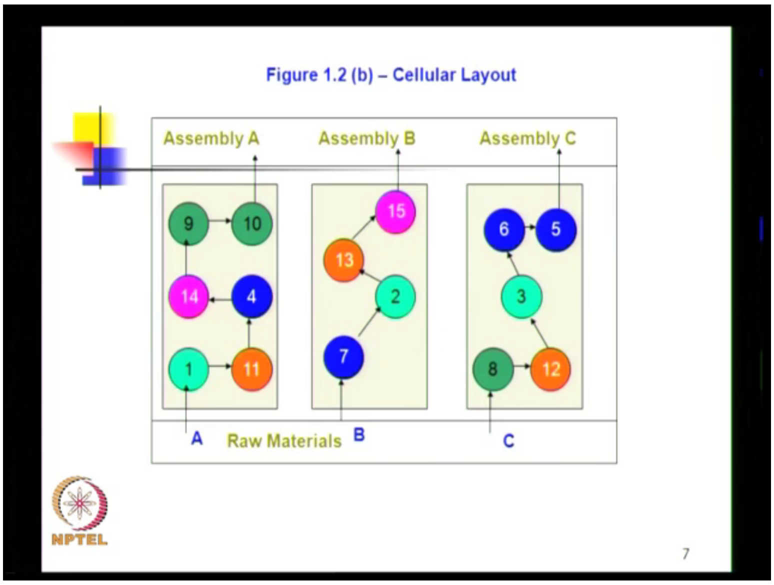

You see that 1 11 4 14 9 and 10 are grouped together. Similarly, if you go back to B. B would require 7 2 13 15. So, B would have 7 2 13 and 15. C would require 8 12 3 6 5. So, C will have 8 12 3 6 and 5, and it goes out. Now this is an example of cellular layout. This is again a pictorial representation of a cellular layout. Now what have we done? We have arranged the same 15 machines that were there in a functional layout. Now the machines inside the cell are not functionally similar machines. They do not have the same color in the earlier one the color represented functional similarity. Now here they are not functionally similar. They are functionally dissimilar. But they are similar, in the sense that together they are capable of meeting the requirement of a set of parts or a part family.

Now, we have to understand that A B and C are not single parts or single components. But A B and C are similar parts or similar components. A B and C are a set of parts, and every if you consider all the parts within the family A, now A will be called as a part family or a component family, which has a family of parts requiring similar machines. Now we will have enough number of parts in A such that these set of parts can be done. In this manufacturing cell number one now the assembly a indicates that A finishes all of these and these parts finish and they go to assembly, but the manufacturing cell is restricted to this part restricted to this 6 machines. Now these 6 machines are such that they are capable of producing all the parts and components that are in part family A. Similarly, the cell B or the second manufacturing cell which contains these machines is now capable of producing all the parts within family B, and similarly this one is capable of producing all the parts within in family C.

So, in this pictorial representation, we have now converted a functional layout, which has 15 machines into a cellular layout which has 3 cells. Now what are the advantages? Now each cell will own this part family A, because every part that is in part family A is now made entirely and completely by the first cell. Now similarly, the second cell will own part family B and the third cell will own part family C.

So, the ownership and responsibility is now towards a set of parts rather than the a process, where the earlier layout had responsibility and ownership for the process. Now what are the other advantages? Other advantages are one could locate A B and C as distinct entities even far away from each other. For example, if we assume this entire rectangle of the screen as the area available, now our cell a can go here cell B can go here, and cell C can go here. It is not necessary that they have to be located very close to each other. Now in this example there is no material movement from A to B or B to C or C to A.

So, they are like entities or factories within a factory. So, material movement is restricted only to within the cell, not between the cells. So, material movement comes down quality of the products increase, because the ownership is on the product, space comes down because let there is less inventory and space requirement comes down, because all these are lo can be located close to each other closer than in the earlier layout. Change over times are not very high, because it is assumed that parts within part family A are similar, and therefore, when they are made on these machines one after another say there are 10 parts in part family A, let us call them A 1 to a 10.

Now we could send them or sequence them in any order it could be A 1 A 2 A 3 up to 10 or it could be another order which would start with A 2 A 5 A 3 A 4 and so on. So, when these parts come one after another on these machines, because they are similar, we would assume that the change over time would be less. So, a changeover time is less, and because change over times are less, we can produce smaller runs which is another requirement of manufacturing the quality gets better and comes close to flawless. The time taken to produce comes down, because material movement time is less batch sizes are small.

So, time taken to produce comes down cost also comes down. The total material movement is also less inventories are small. So, these are the advantages of the cellular layout. So, people started realizing these advantages, and started implementing cellular manufacturing. There with people have been implementing cellular manufacturing. For nearly 50 years now and have been benefited by the implementation. Now so, the first thing that we need to do, when we move to a cellular system from a functional system is to clear the cells, which means to identify the machines that will belong to a machine cell and to identify part families from this set of parts or to identify which part will go to which part family. So, that is called cell design or creating a manufacturing cell.

Now, what are all the various issues in doing this. So, the first issue is called cell formation that is how to group these machines into machines cells, and these parts or component into part families that is called cell formation.

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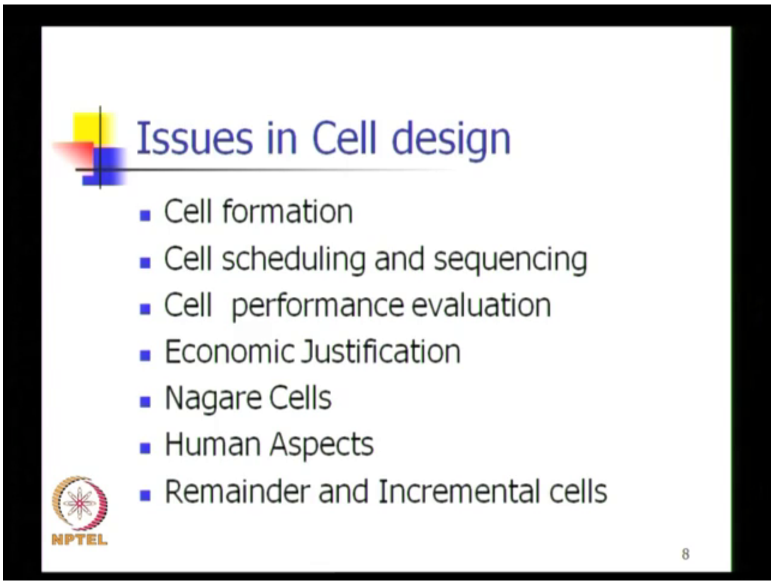

And we will see cell formation in much more detail as we move along in this course. The next thing we have to do is cell scheduling and sequencing. For example, as I mentioned a would represent a part family which could contain 10 different parts. Now we will be able to produce one part at a time in the cell. So, if there are 10 parts in what sequence or order in which we are going to send these parts. Is it going to be 1 2 3 4 5 6 7 8 9 10? Or is it going to be in in a dynamic sense as parts arrive we send them, or is it a predetermined sequence which is a different order or permutation of 1 to 10, is it A 4 A 6 A 5 A 3 A 8, is it something like that.

So, those aspects are called cell scheduling and sequencing. And some of these are dictated by the due dates, the time at which these parts have to be made and sent to the assembly. So, one has to understand or look at ways and means by which we are able to achieve cell scheduling and sequencing. Now cell performance evaluation is another matter that have to be looked at. Now when we do a performance evaluation of this cell, now one has to understand as we create this manufacturing cell and as parts come in do we have enough capacity to do to make the demand of all of these parts. Now with the excess capacity, can we include some more parts? How is the cell performing with respect to meeting the due dates with respect to completing these requirements in time.

So, one needs to understand and do a performance evaluation of the cells. Another aspect that has to be looked at is called economic justification. Now even though in this schematic diagram, we have 15 machines that are there in the functional layout. And exactly these 15 machines are shown in the cellular layout. In practice it does not happen that way several machines which are existing in the functional layout will be retained in the cellular layout, but some of the old machines in the functional layout will not be used for cellular layout.

Sometimes it is from practice it is observed that nearly 10 to 20 percent of the old machines do not figure in the cellular layout. And there could also be addition of machines in the cellular layout. So, when we have addition of machines, then there is a cast associated with it. There is also a certain amount of time which is needed to get these cells to work in steady state, which is also needed which is going to cost us something. There could also be a need to have other support things such as fixture etcetera which may have to be designed or created for the new for the parts as they are operated on newer machines.

So, there is a certain cost that goes in even though the cost is not very high. So, there is an economic justification with respect to making the cells and that has to be made. Then we also look at something called nagare cells. Now nagare cells are very popular. Now if we look at this schematic diagram, we have 6 machines in this particular cell. Now we have some issues like, how many operators are going to be within this cell. Are we going to have one operator for every machine? Are these machines manually operated to require one operator per machine? Or are they automated such that a single operator can handle multiple machines? Now what is a good size of the cell? Can we create cells which have with cells with automatic machines which have fewer operators than the machines? Can we have single operator manned cells? In practice we observe that there are some small cells, which are called single operator manned cells, and these become part of a slightly larger manufacturing cell. Now these single operator manned cells will be will contain automatic machines, let us say 3 machines which are manned by a single operator.

So, the single operator will take a piece and load it on one machine after unloading it, then the operator would take the unloaded piece and put it on to a second machine by which time the manufacturing or the operation would start on the first machine. Then the person will start the second machine, take a piece put it on a third machine. Now the operations will be going on in 1 and 2, and then when he sets up or takes the piece into the third machine and starts by then the first machine would have finished.

The operation sometimes the operator manually unloads, sometimes the machine ejects the piece that has been completed. So, the operator goes around sitting in one position, but handling 3 machines for example, there could be a machine here, there could be a machine here, there could be a machine here, and the operator would take something get this started, take the piece put here get this started, take another piece put it here. By which time this would be over, unloads takes it into the other and so on. Now these kind of single operator manned cells are called nagare cells.

Now, in practice we also have examples where, we could have 2 or 3 operators in a cell and each operator manning a nagare cell. We could also have an example where, there could be 2 operators in this cell 1 11 4 14 9 10, in this cell. We could have 2 operators, and if all of them are automatic machines, one operator would be handling 1 4 and 11. Another operator could be handling 14 9 and 10. We could have 3 operators, where one operator handles 1 and 11, another handles 14 and 4 third can handle 9 and 10. We could actually even have 2 operators, where one person handles 1 14 9, the other handles 11 4 10, but the part movement would still be 1 11 4 14 9 10. In such a case if one operator is doing 1 14 9, the other operator is doing 11 4 10, the first operator will unload a piece from here and keep it in front of 11. By which time this person would have unloaded a piece from 4 and kept it here.

So, this operator would move load this piece into 14, and then go to 9 by which time this person would have unloaded something from 10 and kept it here. So, this person sorry this person will go to 14 then he will unload something from 14 and put it on to 9, and after that from 9 he will unload it and keep it here. Second operator will now walk up to this, take this piece, put it on 10, and whatever is unloaded will go out. So, the part will have a route 1 11 4 14 9 and 10, but the operators one of them will be moving between 1 14 9 the other will be moving amongst 11 4 and 10 respectively. So, various combinations are possible. And these have to be done in a very effective manner. Sometimes it is even possible depending on the part that we are making we could have a different alignment of operators to machines. So, all these flexibilities exist depending on how mature the cell is, and how well the cell has functioned. And how united the people who are working in the cell are with respect to carrying out all of these.

So, there are issues like nagare cells, where are we going to have single operator manned nagare cell a combination of them, or are we going to do what I just now mentioned, that there will 2 or 3 who will have dedicated machines. Now how does this behave when we have manually operated machines, and how does it behave when we have dedicated machines. So, these are all issues that have to be looked at in a cellular manufacturing system. Now we also have to look at human aspects in cellular manufacturing. Now human aspects are very, very important. Now if have a cell for example, a cell that contains 6 machines. And if we are going to assign 2 or 3 operators in that, now depending on the system, so many things have to be done number one is there has to be enough compatibility amongst the cell operators within a particular cell because together they own everything that is happening in that cell.

So, first and foremost is we need a we need compatibility with respect to people. Now that is a non-technical issue, never the less extremely important. Secondly, the skills that for example, if there are 3 operators, the skills that these 3 operators posses. So, the moment I say that there are fewer operators than the machines we are going to assume that there is going to be lot of automation in the machines.

Normally if the machine is manually operated, it is customary to assume that there will be one operator per machine; now most of the times the machines in cellular manufacturing are not manually completely manually operated, but are automatic machines, which means that the processing or the operation happens. The operator need not be present the operators job is restricted to loading and unloading the component on the machine. Now if we have 3 people coming in. Now the skill levels of these 3 people will have to help out each other which have to kind of complement each other. Now the more automation we have the more we are getting into a situation where the operator does only loading and unloading.

So, a skill level requirement for loading and unloading is far less than skill level requirement of actually feeding and carrying out the operation. So, depending on the situation we have to look at the skill level compatibility requirement matching etcetera of the people who are working in the manufacturing cells. So, that is a reason why human aspects are important. Last but not the least this picture is represent some kind of an ideal situation, where these 15 machines are grouped into 3 cells now the way the part family is A B and C are working. There is no material movement from this cell to another cell. Now these cells are independent and these cells can act as factories within a factory, but in practice it is very difficult to have that it is either very difficult to observe that coming naturally in a manufacturing system or it would become a little costly to create independent cells. Also, over a period of time what happens is that the volume and variety that are there in the manufacturing increase, as the volume and variety increases in manufacturing.

Now, can we look at the same thing from existing cells, or do we have to modify the cells. With what frequency do we modify the cells? Now suddenly if we have one particular part or one particular small product with very large volumes. Can we create dedicated cells only for such parts? For example, if there is a company A and a company B. Now company B is a customer and company A let us say make an automobile component, for company B which is a automobile manufacturer. Now if B has a new product which has a very high demand. Now there will be the requirement for A to provide that product to B will be very high. Now can a create a dedicated manufacturing cell to make that component for B; in such cases when we have a cell that is dedicated and makes one particular small product which goes to another company or a set of parts that go into the product.

Now, such cells we describe as incremental cells, which are created to make a particular product or a particular set of parts, exclusively for them now particular, when real situations where the variety is increasing, now when variety is increasing, it invariably results in creation of more cells. Now with what frequency are we going to redesign or recreate the cells. Now in between with increase in volume and variety, can we have a situation where for example, 11 and 13 are 2 similar machines functionally similar? Say, 11 is in cell 1 13 is in cell 2. Now can we have a situation where, there because of increase in volume, the requirement of time on machine one is high machine 11 is higher, and machine 11 does not have a capacity to meet. Now there is some spare capacity available in machine number 13, which belongs to cell number 2. Now can we send some of these parts to cell number 2, only for one operation and bring it back. Because capacity is available in cell number 2.

Now when we start doing that, we are going against the fundamental principle of cellular manufacturing because cellular manufacturing does not want you to move things from one cell to another, whereas, it wants us to move things within a cell. Now when we move something from one cell to another, it is called an inter cell move. Inter cell move is not desirable in cellular manufacturing, but increase in volume and variety would create a situation of increasing the inter cell moves. Otherwise we will have to buy one more machine of 11 and keep it here which is expensive and it may not be utilized fully.

So, as variety increases, can we have different types of design of cellular manufacturing, where we could have something like a service cell and dedicated cells. So, the parts can move to their dedicated cell, and let us say we create one more service cell, which contains one orange machine one blue machine and one green machine. And say that if you need some additional requirement go to the service cell get things done come back to your original cell, but do not go from one original cell to another original cell. I mean idea is very similar in traffic management, now there are times you could see dedicated lines for certain types of automobiles on the road. So, you can switch from your line to a service lane, and then come back to your lane, but you are not expected to switch for a longer period from one lane to another.

Now, you lose a little bit of control in this whole process, but then you do not lose too much. Now can we have this kind of an idea where we create one more service cell here below. And then say that things can move from this 2 service cell things can move from B to the service cell C to the service cell, but not from A to B. Now such things are called remainder cells. Now when do we create such a remainder cell, can we have situations where depending on the volume or depending on the variety do we go for these type of dedicated cells or do we go for remainder cells. Now these are all several issues in cell design or in cellular manufacturing. And we will be addressing some of these issues as we move along in this course. Now to answer the first question of how does one do cell formation. Now there are several ways by which one can do cell formation. There are 3 very popular ways of doing it in practice. In theory there are several algorithms to do that. In in a book called automation production control by Mikell Groover, it talks about 3 ways of doing cell forming cells from a practical prospective. The first one is called a visual inspection. Plus, most of the times people who are within the factory producing a set of parts on a set of machines will know by merely looking at the system which are the parts that go into which families. And once part families are created, they will create the machine cell containing all the machines that can make these parts within the part family.

So, a very traditional way of doing classification is; to do part grouping by inspection by prior knowledge. And then by creating machine cells which are capable of carrying out all the operations for the part family. So, part families can be formed by visual inspection, and part families can also be formed by what is called classification and coding. So, the second way by which we do is called part classification and coding; where the parts have what are called design attributes, and they also have what are called manufacturing attributes.

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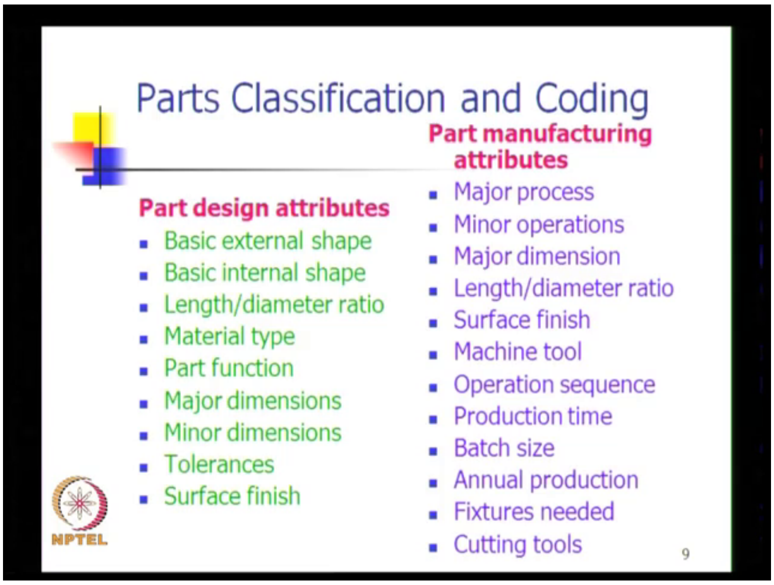

Some examples of design attributes and manufacturing attributes are given here.

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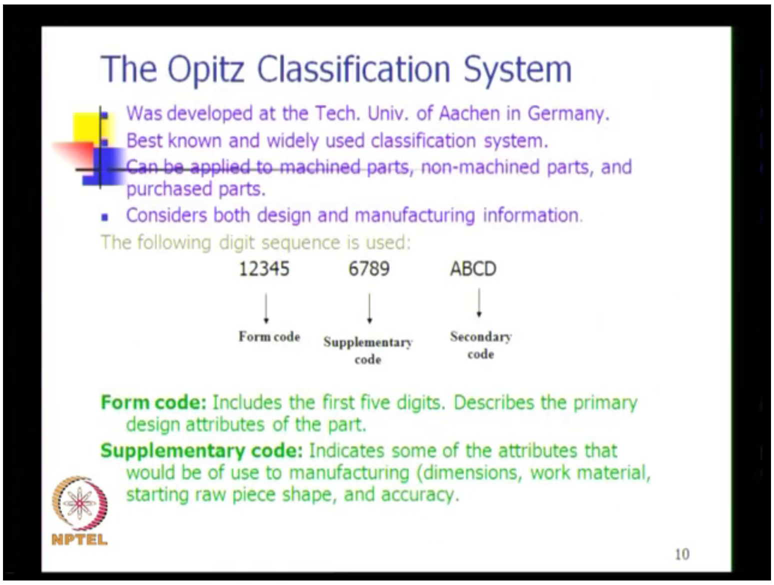

And depending on these design and manufacturing attributes, we can now form a code and classify the parts based on these codes. A very popular classification system is called the Opitz classification system, and the Opitz classification system has 5 digits which represent the form code. Another 4 digits for the supplementary code and another 4 digits for the secondary code. So, the Opitz classification system has a code, which is alpha numeric it has 9 components where there is numbers, and there are 4 components where there is alphabet. And depending on the form code and the design requirements, and manufacturing requirements the classification and coding system can be used to create a unique code for every part. Now once the unique code for every part is created, now there are as many codes as the number of parts, and simply sorting the codes would give us a part classification. An equivalent thing that we can see in practice is when a student enters a university or a college. The student is given a unique roll number. In most of the situations the roll number contains certain components. And these components would be the branch of study, the year of entry the department to which the student is assigned and the certain running serial number.

So, typically a roll number takes care of a code through which an a particular student in a university can be identified. In a similar manner a part that is inside a manufacturing system is now identified in terms of a part code. Now students within the university now can be grouped or classified depending on several aspects of the code which is the roll number.

So, one could group them or classify them based on year of entry, they could be classified on branch of study, they could be classified on the department to which they are attached in a similar manner these parts can also be classified depending on the design attributes and on the manufacturing attributes. From which parts families can be formed, and once the part families are formed, it is possible to form machine cells by combining and taking machines that are required to produce all the parts with that are there in the part family. So, the 2 methods commonly used are the visual inspection method, and the classification and coding method.

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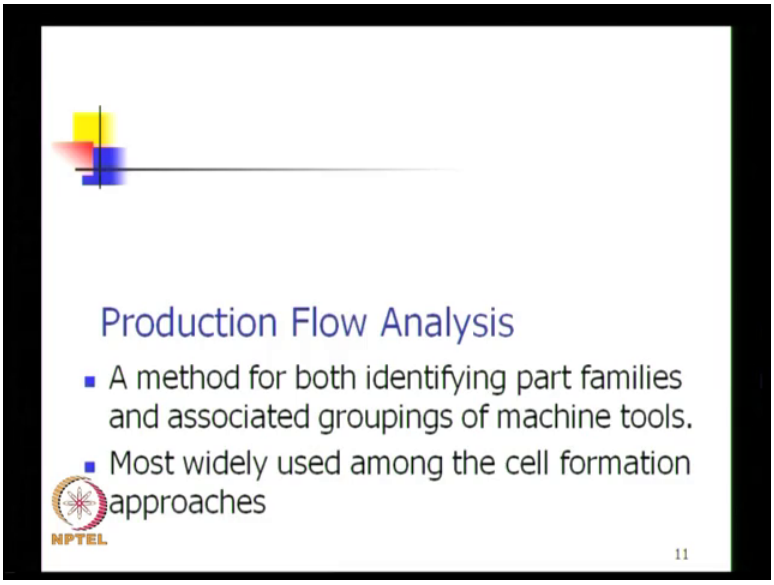

And the third one is called production flow analysis. Now this method called production flow analysis was introduced by Burbidge. Burbidge wrote a series of articles in cellular manufacturing and group technology. Starting from the early 6ties and introduced the idea of production flow analysis as a way to execute group technology or cellular manufacturing.

Now, there are several versions of production flow analysis, and what we will see in this course is called a manual method of production flow analysis which came in Burbidge's paper in 1997. So, production flow analysis is a method, which is used for identifying part families as well as machine groups. Grouping of machine tools machine tools is a machine. So, grouping of machine tools simultaneously not sequentially, but simultaneously; the other 2 methods which are the visual inspection, and classification, and coding invariably do it sequentially where part families are identified first, and then machine cells are identified in production flow analysis they are identified simultaneously. It is quite extensively used amongst the cell formation approaches. It is a very simple approach and it any practicing person can quickly understand and implement production flow analysis. So, we will be seeing production flow analysis in a subsequent lecture in this course. But right now, I have just introduced 3 simple ways or practical ways of finding part families and machine cells.

We will go into detail on production flow analysis in the next lecture. There are also several theoretical models which are which are available which have come from contributions in academic research. The cell formation problem can be formulated and solved as optimization problems. And there is a lot of research which describes both exact or optimal methods and heuristic methods to create the manufacturing cells and part families. So, we will be seeing some of the optimization-based approaches to cell formation or heuristic approaches to cell formation also in this course. Now we will be looking at cell formation in a in the subsequent lectures.

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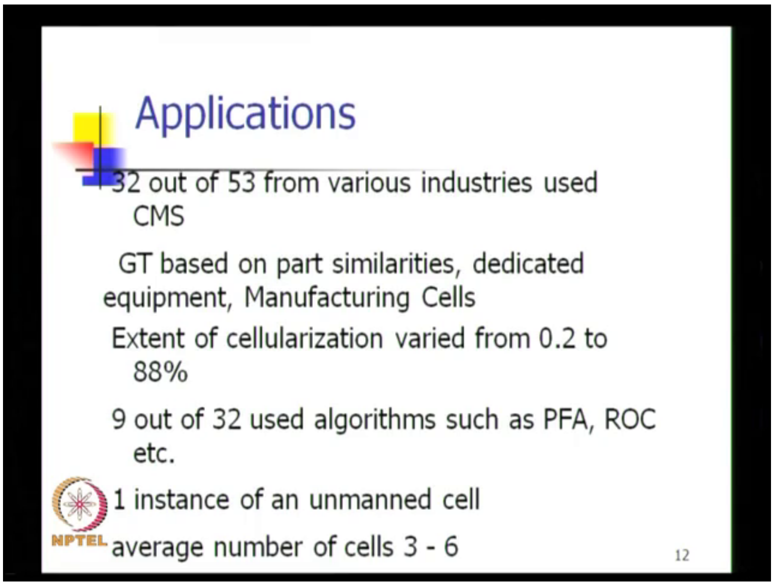

But let us also look at some aspects of applications of cellular manufacturing. Now there is we have already mentioned about the surveys that authors some authors have carried out to see or to study the applicability or application of this area. There is a survey by higher and (Refer Time: 49:12) which happened in 1987 which was published in 1987. And they surveyed 53 companies from various industries, which had said they that they have implemented cellular manufacturing in 19, during the period 1987. Now they from their survey of 53 companies, they understood that 32 out of the 53 actually used cellular manufacturing as early as 1987. They were also able to see examples of cellular manufacturing application based on part similarities. That we spoke about based on dedicated equipment that we spoke about dedicated cells and based on other manufacturing cells.

Some important things are the extent of cellularization varied from 0.2 percent to 88 percent. Now extent of cellularization means the percentage of business are in terms of money value or dollar value in that case. That is generated out of products made in cells. So, this shows that at that time there are one or 2 companies which had maybe one cell or 2 cells, which created only 0.2 percent of the revenue. While there were companies which had 88 percent of the revenue generated from products or parts made in cells.

So, there were companies that have used this extensively. It is also true and acceptable that all 100 percent does not come, because some facilities have to be kept as central facilities and cannot be put into cells. So, of these companies also said that they used algorithms such as production flow analysis that we are going to see another algorithm called rank order clustering that we are going to see. So, some of these companies that said that they had used these algorithms to create cells, there was only one instance of an unmanned cell and in their survey the average number of cells ranged from 3 to 6.

So, with you have seen little bit some aspects of application of cellular manufacturing. We will continue with some more discussion on the applications and issues of on cellular manufacturing. And then we will move towards algorithms for cell formation and discuss production flow analysis in detail in the next lecture.