Manufacturing Systems Management

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Lecture - 26
Cell layout, Introduction to Just-in-time manufacturing

In this lecture we discuss some aspects of Cell Layout.

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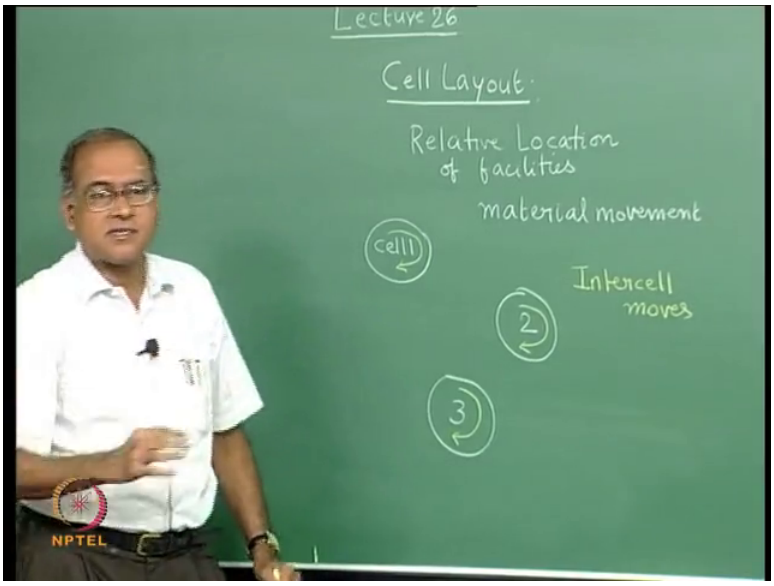

Layout essentially deals with Relative Location of facilities: relative Location of facilities within a given area. In a traditional layout model, we have several facilities or departments. And there is a lot of material movement among the departments. So, when there is material movement among various departments, then it is necessary to place departments that have large material movement close to each other. And departments that have less or few movement of material are placed away from each other. So, a layout essentially addresses this idea. Now let us look at Cellular Manufacturing and see where these principles of layout are applicable. And then discuss 1 layout model which is popularly used.

So, if we look at a Cellular Manufacturing system let us say a Cellular Manufacturing system having 3 cells which we call cell 1, cell 2 and cell 3. Now there are machines inside each cell and let us say there is unidirectional flow of material within this cell. By the very definition of a cell, we are looking at a set of machines and a set of parts or components and a set of people who will be allocated to this cell such that this cell is completely self-contained. In an ideal situation, there should be no material movement amongst these cells. The material movement amongst these cells is caused by Intercell moves. And the very purpose of Cellular Manufacturing is to avoid or minimize Intercell moves. So, normally there will not be so much of movement of material amongst the cells.

And therefore, the scope and opportunity to actually look at layout models where we try and place cells that have more material movement closer to each other. Such models have limited scope in the context of Cellular Manufacturing. If we have a system where we create cells and yet there is a significant Intercell move then models for relatively placing these cells can be looked at.

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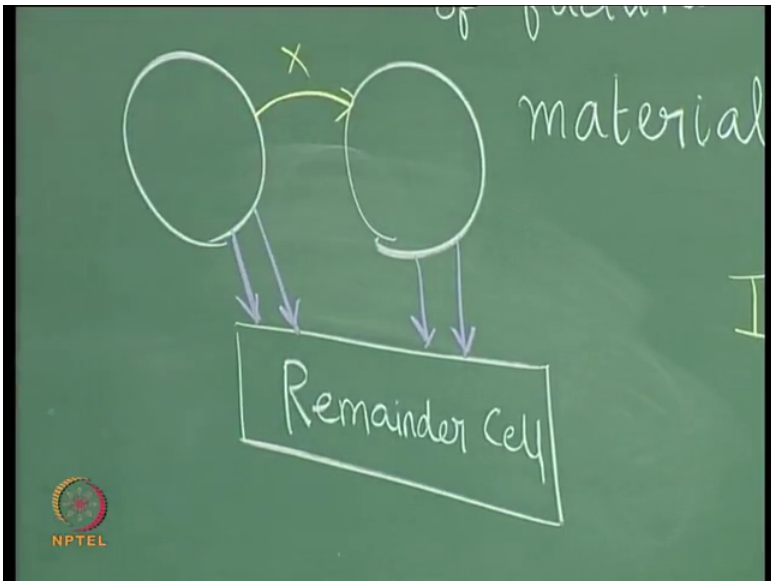

We also spoke about different types of cells and one of the things that we spoke is something called a Reminder Cell or a service cell and cells that are located like this where there is a large material movement which is allowed and permitted. While this material movement is not there or it is minimized.

So, in the context of Reminder Cells one could think in terms of a lot of material movement and where do we place the service cell. Most of the times a simple solution is, place the service cell in the middle and keep the rest of the cells around it so that the material movement can be handled. In this context there could be some scope to apply traditional layout models in the context of relatively placing the cells. So, with this background we look at one basic model where we study the layout problem through an example and then later relate it in the context of go back to what we said now and relate it to where exactly this model fits in the context of Cellular Manufacturing.

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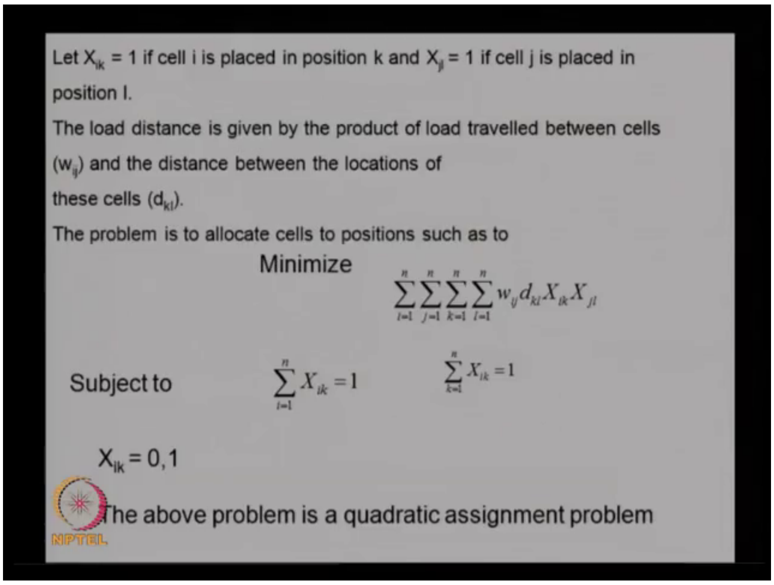

Now, if we have multiple cells and there is material movement amongst the cells then we could think in terms of formulating a problem which talks about the location or layout of the various cells into various positions. So, in a typical layout problem we could think in terms of 3 or 4 departments or any number of departments and the certain number of sites or places where we can locate these departments relatively.

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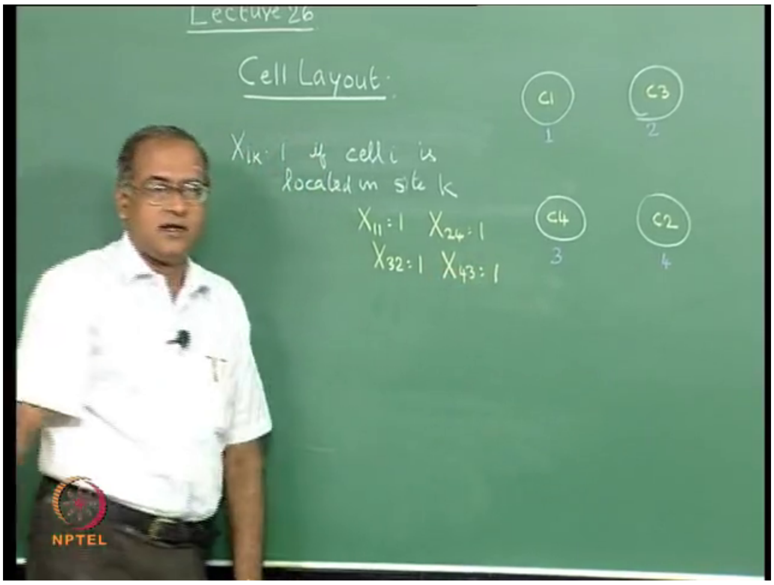

And we will use a notation where X i k equal to 1 if department i or cell i is located in site k. It is like saying that, if we are looking at 4 cells and 4 places. It is like saying the 4 places could be like this. We could call these 4 places as 1, 2, 3 and 4. We could call them as 1, 2, 3 and 4. And then, we could we want to find out where we are going to locate each of these cells. We could have a solution where cell 1 is put here, cell 3 is put here, cell 2 is put here and cell 4 is put here. This could be 1 solution. Because cell 1 has a different set of machines, cell 2 has different sets of machines and so on.

Now if we do this, then X i k equal to 1. If cell i is located in site k or position k there in the slide I have used a notation X j i k equal to 1 and X j l equal to 1. So, this would be represented by a solution. X, cell 1 goes to site 1, X 1 1 equal to 1. Cell 2 goes to site for X 2 4 equal to 1. Cell X cell 3 goes to site 2. X 3 2 equal to 1 and X 4 3 equal to 1 is represented by this solution. So now what we can do is if now the question is given these sites, given these sites, which cell will go to which site. Now what are we trying to minimize or what is the objective. The objective is, there is going to be a certain material movement amongst the cells.

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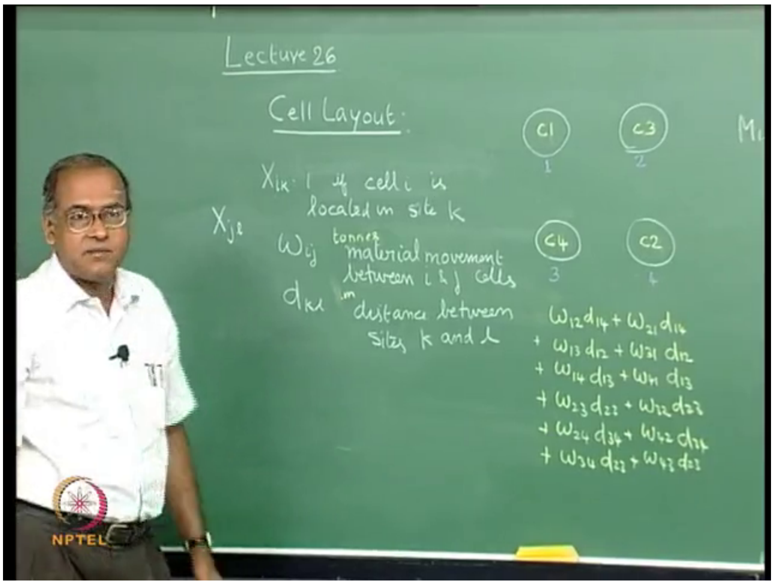

So, if we say that W i j is the material movement between i and j cells. Cells i and j. d k l is the distance between sites k and l. Distance between sites k and l. And if we consider a solution that we wrote here c 4 was here, c 2 was here, c 3 was here, c 1 was here. This was the solution we had. Now if we choose this solution then, what is the amount of material movement in terms of load and distance? For example, this could be given in terms of load, ton or kg or whatever. In a traditional layout literature, this will be in tonnes and this could be in kilometers or meters.

So, if we have a solution like this, what is the material movement? Material movement will be between cells 1 and 2, there is a material movement of W 1 2 and that travels a distance d 1 4. There could also be a material movement of W 2 1 which also moves a distance d 1 4. Some material can move from this to this. Some material can move from this to this. We will assume that the distance is the same.

There will be now between 1 and 3, W 1 3 d 1 2 plus W 3 1 d 1 2; between the cells 1 and 4, W 1 4 d 1 3 plus W 4 1 d 1 3; between 2 and 3, W 2 3 d 2 3 plus W 3 2 d 2 3; between cells 2 and 4, W 2 4 d 3 4 plus W 4 2 d 3 4, because this distance is between 3 and 4 between 3 and 4 W 3 4 d 2 3 plus W 4 3 d 2 3. So, this will represent the movement in terms of ton, kilometer or kg, meter essentially a load into distance is represented by this. So, the problem is, given a certain allocation of cells to sites or facilities to sites we can compute this movement.

Now, what is the allocation that will minimize this movement? Because these sites are given here, d 1 2 can be taken as d 2 1 symmetry will normally hold between distance between 2 points d i j is equal to d j i. Therefore, I have written d 1 4 in both the places and I have not written d 4 1. For the ease of simplicity we could assume that even the W's are symmetric. Normally it need not be, but we could assume that W's are symmetric. So, if W's are symmetric then each of this will be 2 times W 1 2 d 1 4, 2 times W 1 3 d 1 2 etcetera. There will be only 6 terms instead of 12 terms with each term multiplied by 2. So given a certain allocation i can find out this, what is the allocation that will minimize this. So, what are we trying to do? We are trying to minimize.

Now, what is the cell load between 1 and 2? What is the cell load W 1 2 into d between cells 1 and 2, W 1 2 d 1 4. So, between if facility i is assigned to cell k and facility j is assigned to site l then the material, the amount of movement is W i j and the distance is d k l. i goes to k, j goes to l. Material movement is i to j. Distance is k to l.

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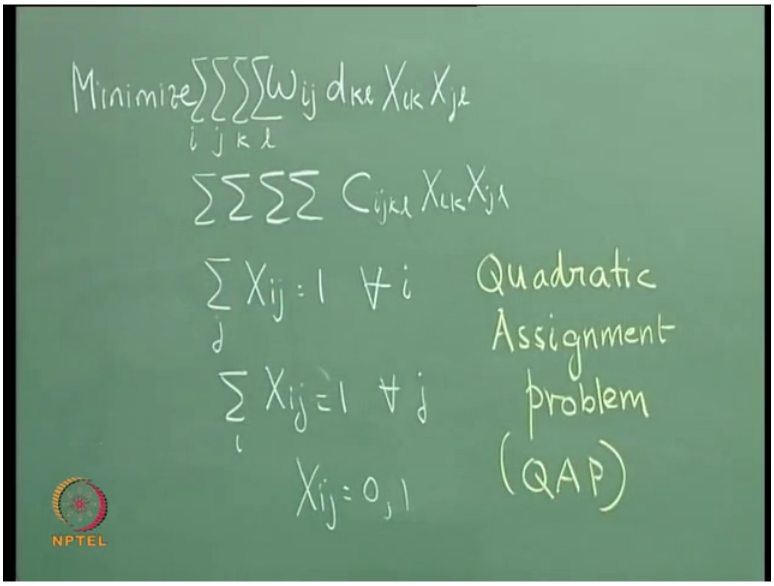

So, W i j into d k l is the thing that we are trying to minimize; summation of that. And that will be multiplied by X i k into X j l. Because only when X i k and X j l equal to 1, the product is 1 and this multiplication is to be minimized. This is to be summed over 4 summations 1, 2, 3, 4 i j k l W i k W i j d k l. This is generally written as 4 summations, C i j k l X i k X j l. Subject to the condition that each cell or department will go to only 1 position. So, sigma X i j equal to 1, summed over all positions for every i, for every department. And sigma X i j summed over i equal to 1 for every j that each site will get exactly 1 department. Each department goes to exactly 1 site; each site goes to exactly 1 department and X i j equal to binary. It is either 0 or 1.

Now, this problem is an optimization problem. This problem looks like an assignment problem from here. It has the assignment constraints sigma X i j equal to 1 and for every i sigma X i j equal to 1 for every j. So, it has the assignment constraints. The objective function term looks like a C i j X i j term, but it has a product. So, it is quadratic because it has a product and therefore, this problem is called the quadratic assignment problem. It is called QAP. The objective function is quadratic. The constraints are linear and the variables are binary.

So, it is a quadratic assignment problem which is given like this. Now the quadratic assignment problem also is a difficult problem to solve; particularly when the number of variables increases. So, quadratic assignment problem also many times we solve this problem heuristically. So, we are now going to show one example of a heuristic algorithm which we could use to solve the quadratic assignment problem.

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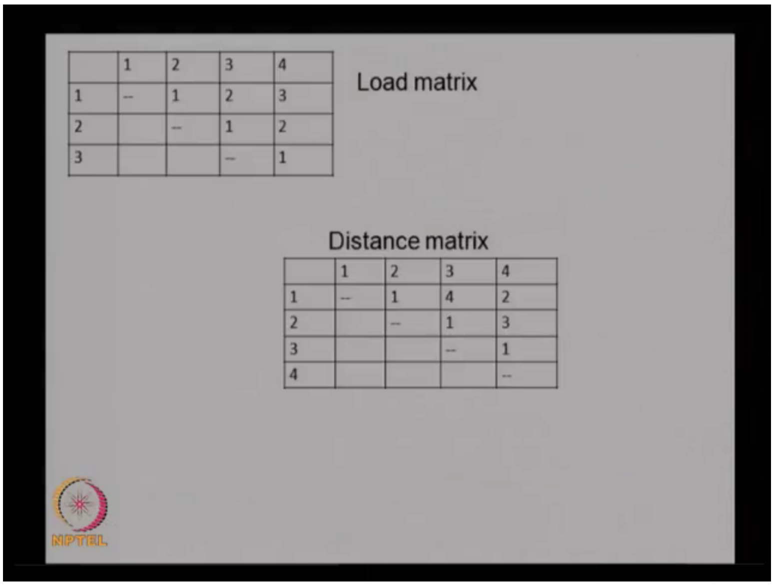

Load matrix

	1	2	3	4
1	--	1	2	3
2		--	1	2
3			--	1

Distance matrix

	1	2	3	4
1	--	1	4	2
2		--	1	3
3			--	1
4				--

So, we take this particular example where we have 4 departments and 4 sites. The loads are W 1 2 is 1. We assume symmetry. The load matrix is a W i j matrix. The top matrix is the load matrix where you can see symmetry there. Only 3 rows are given, the fourth row is not required because of symmetry. The distance matrix is also a 4 by 4 distance matrix.

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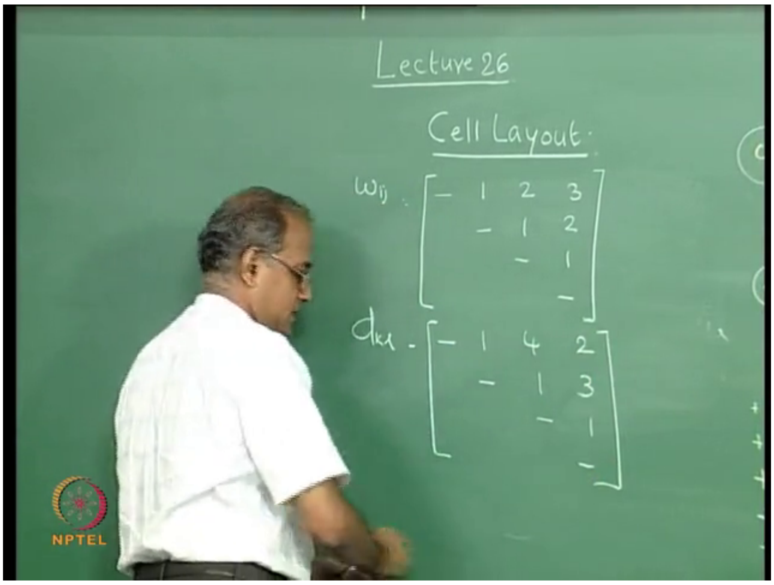

So, what we will have is we will. So, W i j is 1, 2, 3, d k l is 1, 4, 2, 1, 3 dash.

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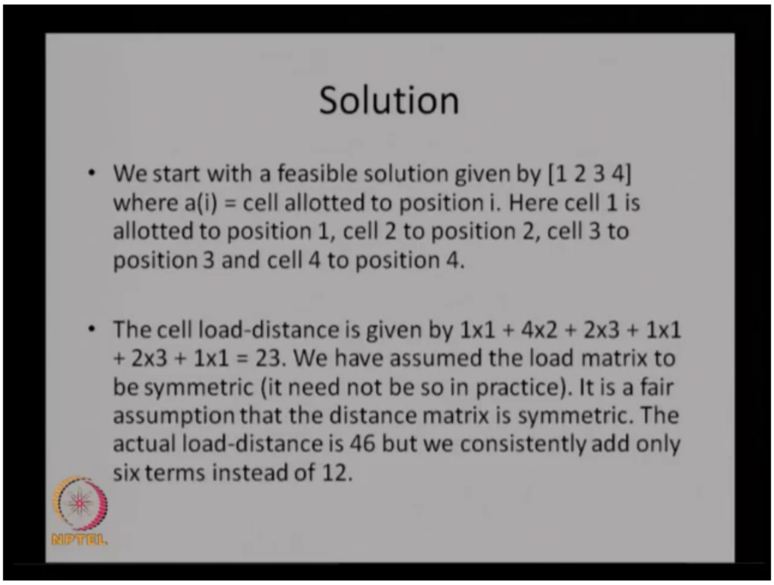

So, we could start with a solution given by 1, 2, 3, 4.

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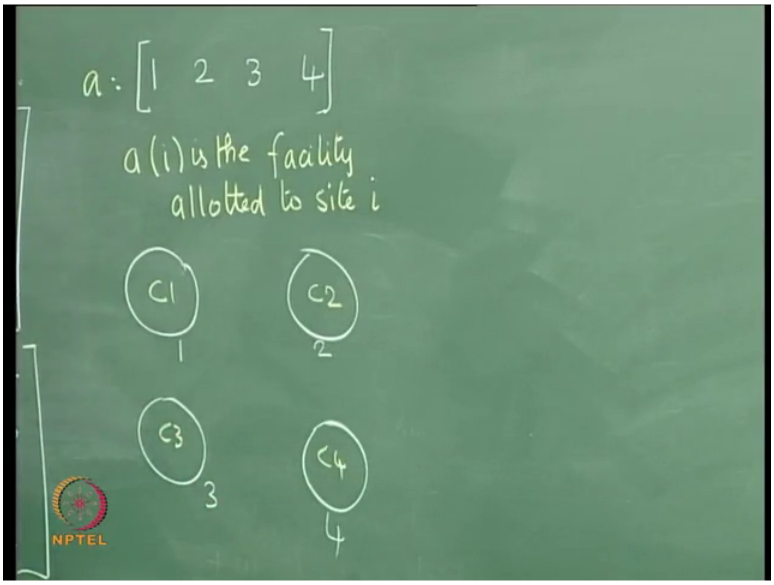

Now, we have to define this. This is a equal to 1, 2, 3, 4 is a solution. Where a of i is the site, is the facility allotted to site i. For example, if there are 4 sites 1, 2, 3, 4 would these are the sites 1 2 3 4. So, this solution is cell 1, cell 2, cell 3, cell 4; so this is clear, but if we have a solution which is.

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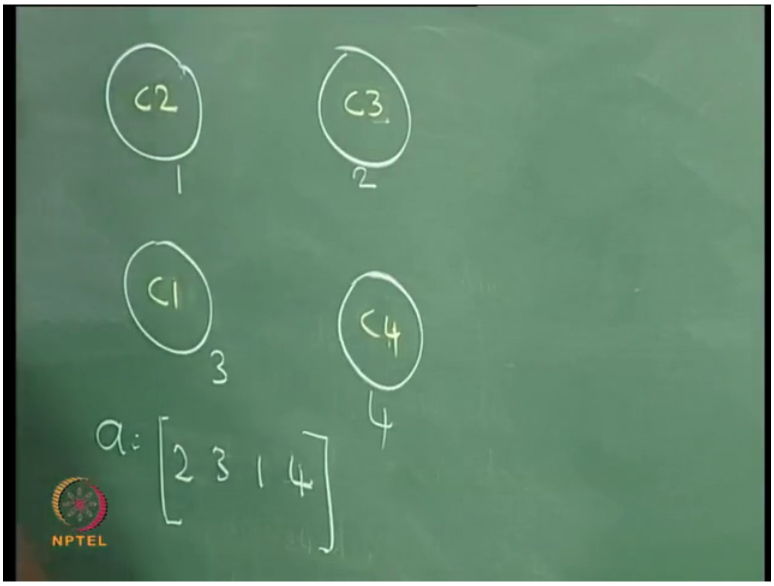

But if we have an a equal to 2, 3, 1, 4. Now this is the facility allotted to site 1 is 2. So, this is c 2. Facility allotted to site 2 c 3, c 1, c 4. This is what it means. So, we would begin with the solution 1 2 3 4.

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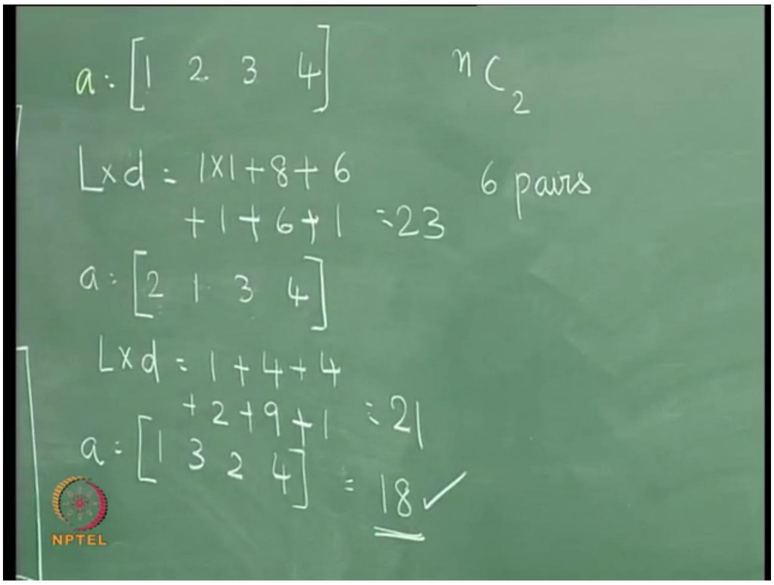

So, if we begin with 1 2 3 4, the objective function are load into distance for 1 2 3 4 will be W 1 2 into d 1 2. W 1 2 is 1, d 1 2 is 1; 1 into 1 plus W 1 3 d 1 3, 4 into 2, 8; W 1 4 d 1 4, 6; W 2 3 d 2 3, 1; W 2 4 d 2 4, 6; W 3 4 d 3 4, 1. So, this will be 1 plus 8, 9, plus 6 15, 16, 22 plus 1, 23. So, actually multiplied by 2 considering the symmetry here and symmetry here as i mentioned, the symmetry here can be accepted. This symmetry is assumed so that 46 becomes 23 which is what is shown in the slide that cell load distance is given by 23.

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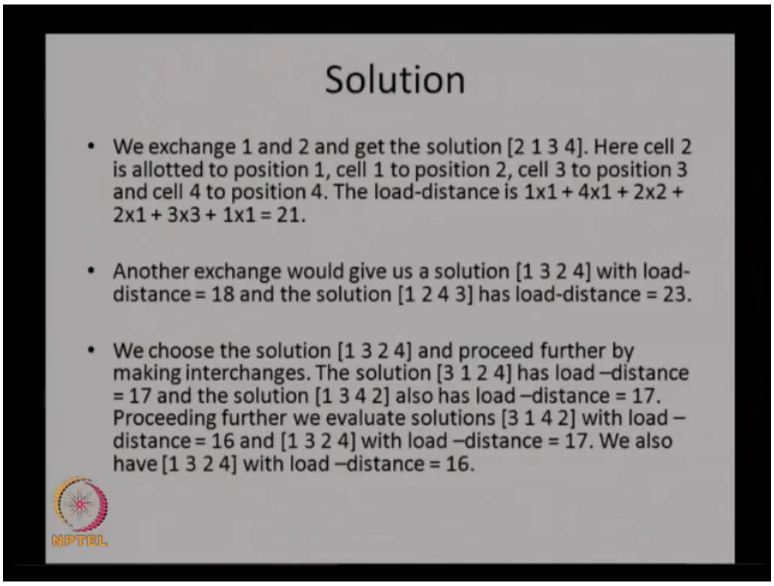

Now, we use an interchange algorithm. And then we try and see evaluate a solution. We could use an interchange algorithm where we interchange 1 and 2 and we get 2, 1, 3, 4. These 2 positions are interchanged. Now for this, l into d is given by, W 1 2 d 2 1, 1 into 1 plus W 2 3 d 1 3, W 2 3 d 1 3, 4; W 2 3 d 1 3, 4. W 2 4 d 1 4, W 2 4 d 1 4,4. W 1 3 d 2 3, W 1 3 d 2 3 plus 2; W 1 4 d 2 4, W 1 4 d 2 4 plus 9; W 3 4 d 3 4, 1 into 1.

So, this would give 9 plus 2, 11 plus 9, 20, plus 1, 21 which is shown in the slide as a solution which is 21. So, we try another interchange, we try another solution a starting from this. Now we get another interchange could give us a solution 1, 3, 2, 4. So, 1 and 2 interchange is given here. Now 2 and 3 interchange would give us 1, 3, 2, 4. 2 and 3 interchange would give us 1, 3, 2, 4. So, this gives a load distance of 18.

So, a typical pairwise interchange algorithm will take. If there are n departments, we will do each pair so there are n c 2 pairs. So, there will be n c 2 pairs and we can do all the n c 2 pairs. In this case there will be 6 pairs. There will be 6 pairs. And we can get the best solution out of the 6 pairs. So, when we do this we get a solution here with distance equal to 18. Now we after doing these 6 pairs we will update this solution.

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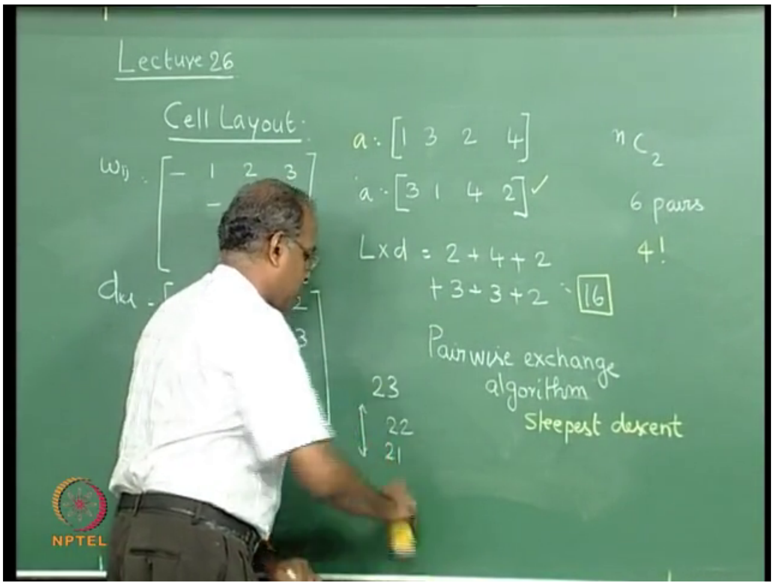

And then we will take the 1, 3, 2, 4 as a starting solution. We will take 1, 3, 2, 4 as a starting solution. And then we can do 1 more interchange where we would have 3 week after some couple of pairwise interchanges, we would have a solution 3, 1, 4, 2. Now let us evaluate for 3, 1, 4, 2, l into d.

So, the l into d for this will be W 3 1 d 1 2 or W 1 3 d 1 2. W 1 3 d 1 2 is 2. W 3 4 d 1 3, d 1 3 is 1. W 3 4 d 2 3 is 4. W 3 4 is 1, so 2 plus 4; W 3 2 or W 2 3 d 1 4. W 2 3 d 1 4 is 2. W 1 4 d 2 3, W 1 4 d 2 3 is 3. W 1 2 d 2 4, W 1 2 d 2 4 is another 3; W 2 4 d 3 4, 2 plus 1, 2. So, this is 8 plus 3, 11 plus 3, 14 plus 2, 16. So, we can continue to do these pairwise exchanges and for this problem, we realize that the best solution is 3, 1, 4, 2 with value equal to 16.

We need to answer 2 questions before we freeze on this algorithm. If we start with n, first of all the Quadratic Assignment Problem assumes that there are an equal number of sites and equal number of facilities. So, if you have 4 facilities, 4 departments, 4 cells whatever you may call there are 4 sites. Therefore, there are every pairwise there are 6 pairs which is 4 c 2 pairs which can be evaluated at any given point. The total possible solutions of allocating 4 departments to 4 positions or sites are given by 4 factorial; 4 factorial is 24 c 2 is 6.

So, every time we do a pairwise exchange that we complete, we will be doing a subset of the maximum possible which is the factorial. Then we take the best and then we continue to do the pairwise exchange. Sometimes we end up repeating a solution which we already evaluated and sometimes we end up creating new solutions because the positions have changed. And because certain portions have changed certain computations also change. So, at the end when we are not able to improve the solution we stop by giving it as the best solution.

So, this method is called a Pairwise exchange heuristic. You can call it Pairwise exchange algorithm or Pairwise exchange heuristic. So, when we do 1 round of pairwise exchange and we evaluate 6 solutions or n c 2 solutions, we take the best out of the n c 2, we update and we proceed. For example, if we had started with we started here with a solution that had a load distance of, we started a solution that had 23 and then we moved to a solution with 21.

Now, let us assume we started with 1, 2, 3, 4 which is 23 and the best out of the 6 exchanges gave us 21. There let us assume there was another solution with 22 which was better than 23. Now we did not update this 22. As soon as we got something less than 23, but we waited for a set of n c 2 to be done and picked the best. It is a minimization problem. So, we essentially picked the 1 which had the largest difference. Now this is called using a method of steepest descent which means you are here at 1 point with 23 and from there you move to the point of Steepest descent which is the best solution that you get in that cycle. So, this is pairwise exchange algorithm following method of Steepest descent. Steepest descent is well known it is a well known heuristic to solve Quadratic Assignment Problem. And we have used this Steepest descent heuristic from old man to do this algorithm. Now does this give the optimum solution? It does not guarantee the optimum solution. Many times it gives a good solution, but does not guarantee an optimum solution.

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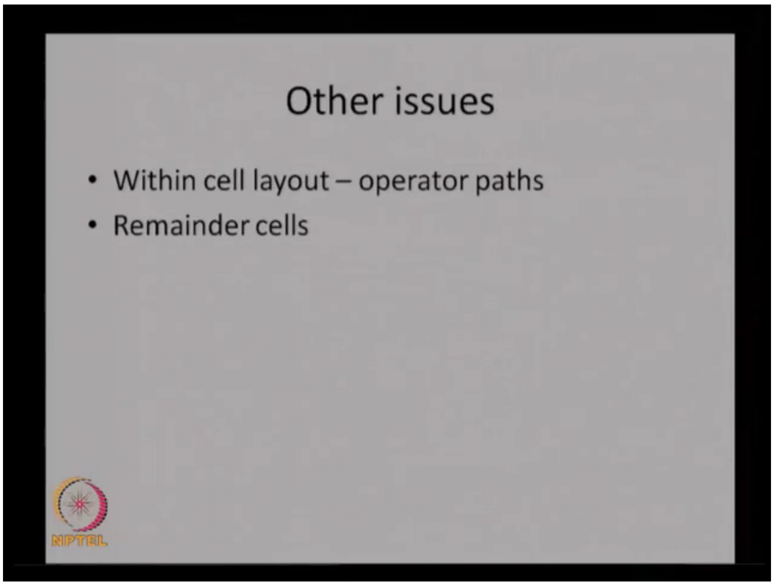

So, let us again go back to the different types of Cellular Manufacturing systems and try to position some aspects of layout on the different positions.

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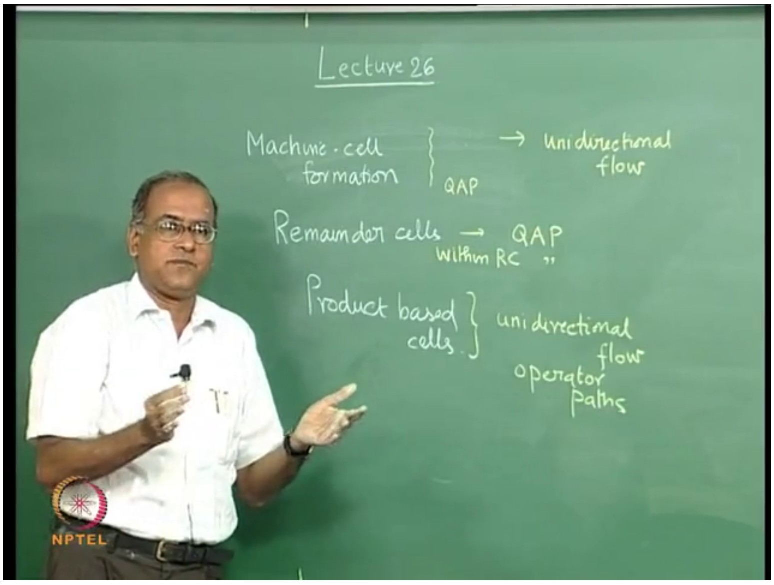

So, first is the Machine cell formation, Reminder cells, product based cells. So, the Quadratic Assignment Problem that we saw can be applied very close to only the Remainder cell, because there is a lot of material movement amongst the regular cells and the Remainder cell. So, the question of where do I position the remainder cell comes. So, a Quadratic Assignment Problem addresses this.

Now as far as machine parts cell formation, there is a very limited application of Quadratic Assignment Problem particularly when we have large number of Inter cell moves. So, we do have situations when we have this. Now we could even, within the Remainder cells if the Remainder cell acts like a functional layout there are departments within the Remainder cell and we can look at movement amongst those departments. So, here also within the Remainder cell we could use the Quadratic Assignment Problem.

Now, when we move towards product based cells then we will we are not going to look at Quadratic Assignment Problem because we will have very minimal Inter cell moves even if it moves from one cell to another before it moves to the assembly. So, here the only thing that we have to look at is unidirectional flow and operator paths. Here also, the only aspect that we have to look at is unidirectional flow. Many times here we assume that we are not going to have fewer operators and machines. Here we normally assume that there will be as many operators as the number of machines.

So, operator path problem and layout, layout to accommodate the fact that operator paths do not cross each other. So, such things are not very relevant here. The more important thing in all of them particularly here and here, is to space. To keep the machines sufficiently close, not too close because you still need some space for some minimal work in progress inventory plus we also have to follow the regulations of minimum distance between the machines in a plant. But the less space that we utilize, the less inventory that we will hold. So, layout and location essentially deal with some aspects of Quadratic Assignment Problem, but more emphasis on unidirectional flow keeping the machines in such a manner that there is unidirectional flow and operator paths not crossing each other. Now with this we come to another important aspect which we can address it in 2 ways.

We move to another part of this course which is called just-in-time Manufacturing system. Just-in-time manufacturing systems can also be seen as a way of cell control. When we started this lecture series, we started with the requirements of manufacturing and then we spent understanding Cellular Manufacturing and the various aspects of Cellular Manufacturing.

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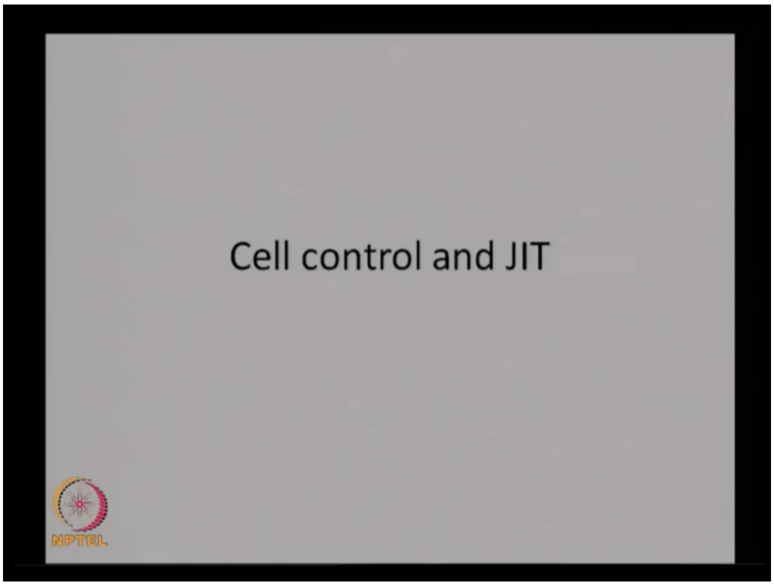

The topics that we would be looking at, the topics we would be looking at in this course start with Cellular Manufacturing, just-in-time Manufacturing systems, synchronous manufacturing or theory of constraints and flexible manufacturing systems.

Now we move from Cellular Manufacturing Systems to JIT or just-in-time manufacturing systems. Even though they are different, they have a lot of similarity and commonality between them when it comes to implementation. While just-in-time systems and it is ideas can be implemented even in a non cellular manufacturing context. A large amount of benefit has been attained by companies when JIT or just-in-time is implemented along with Cellular Manufacturing.

Just in Time can also be seen as a way by which we take care of cell control or the amount of inventory within a Cellular Manufacturing system while Cellular Manufacturing system can be thought of as a kind of manufacturing methodology, where dissimilar machines are brought close to each other. There is a change in the layout. just-in-time can be seen as a philosophy which can be applied to manufacturing systems. So, any type of manufacturing system can benefit by applying the just-in-time philosophy.

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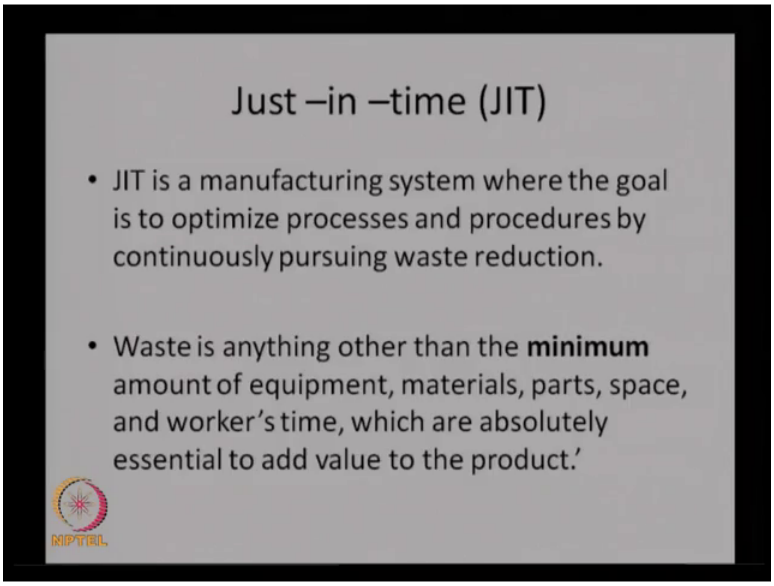

So, we now ask a few simple questions what is JIT or what is just-in-time manufacturing. A very simple definition of just-in-time is, it is a manufacturing philosophy or a manufacturing system or a manufacturing philosophy where the goal of the organization is to optimize processes and procedures by continuously pursuing waste reduction. Waste reduction is the key word in just-in-time. Many times when we are asked to define just-in-time, we end up defining it as produce something just-in-time or produce something when it is required. While these are also good definitions of just-in-time manufacturing system. The best definition is, it is a philosophy or a method by which we optimize processes and procedures by continuously pursuing waste reduction. When it is applied to manufacturing it is a manufacturing philosophy or methodology. As a principle it can be applied to any system where we reduce waste or pursue waste reduction. So, it leads us to the next question, what is waste. A very good definition of waste which is given by the Japanese particularly from Toyota production systems is that waste is anything other than the minimum amount of equipment, material, part, space and time, workers time which are absolutely essential to add value to the product.

So, when something is manufactured, we should have an idea of how much of equipment is required, how much of material is required, what are the exact parts that are required, how much of space is required to manufacture and how much of time is required to manufacture. If we end up providing more than the minimum of these that are required, then we are wasting one of them. So, if we want to pursue waste reduction, we have to ensure that we do not use more than the minimum effort we could combine all of these into 1 word called effort. And say, to make this product, a certain amount of effort is needed. If we end up spending more effort on it which essentially adds up to spending more cost then we are wasting something.

So, wastage of equipment, material, part, space and time result in wastage of money. And the organization ends up producing these items much costlier than what they should be producing. So, by continuously pursuing waste reduction we are directly trying to reduce the cost or price or the amount of money that is spent to make a product. Therefore, just-in-time manufacturing and lean manufacturing have a lot of things in common. Many places people use lean manufacturing and just-in-time manufacturing alternatively. When we look at the definition of lean manufacturing there also we focus on pursuing waste reduction. Thereby the cost of producing something is minimized.

In JIT, we do not explicitly say that the cost of production is to be minimized. We say that there has to be waste reduction and waste elimination. Another very simple way of defining what is a waste is that, when we actually take a product and find out the cost and split it into various costs, there as soon as we do that we understand that some of these expenses have come because of inefficiencies in the system, because of wastes in the system and these are costs that we cannot charge to the customer or these are costs that the customer would not be willing to pay if the customer knew that it was a waste.

So, in one of the visits to a company that I made several years ago, when the organization was trying to define JIT and define waste, a senior executive said waste is something that you cannot charge on to your customer. Your customer would not like to pay for it. The moment the customer knows that it is non value added or is it in excess of what is to be spent or what effort is to be spent on the product. So, definition of waste and understanding waste is a very important part of understanding just-in-time manufacturing system.

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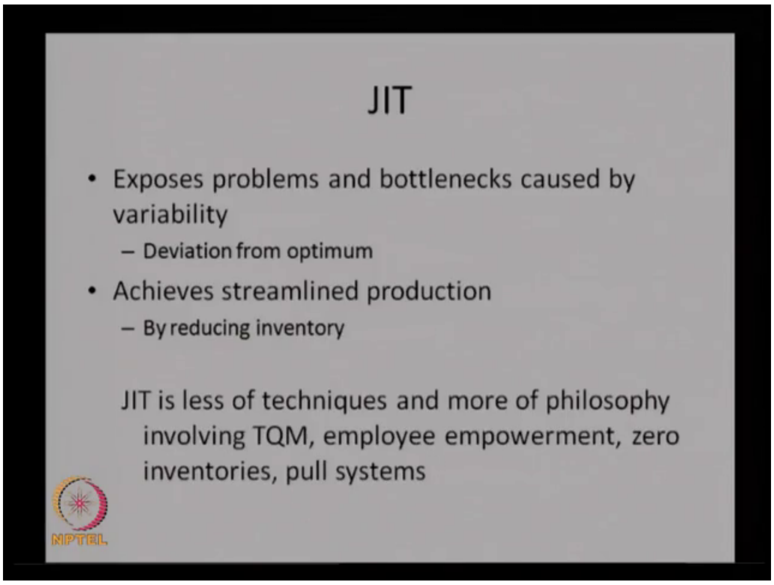

What does just-in-time manufacturing system do? JIT essentially exposes problems and bottlenecks caused my variability. Now JIT as a system, can particularly when applied to Cellular Manufacturing, can handle increase in volume, can handle slightly more volume. JIT systems suffer a little bit when there is more variety into the production. Or JIT will have a way by which it will expose variation and variability.

We will see that as we move along in this lecture series. JIT also helps in achieving streamlined production very stable and streamlined production particularly by reducing the inventories in the manufacturing system. So, JIT is less of techniques. You will not find too many formulae or you will not find too many equations nor would you find too many things like changing the layouts and so on.

It is a philosophy, it is a way of life; there are simple things which have to be pursued continuously all the time without a break so that certain objectives can be achieved. So, the next one which says JIT is more of a philosophy that involves TQM that is Total Quality Management, employee empowerment - giving empowerment to the employees and operators who work in the cell, 0 inventories - try to have minimum inventory in the system and follows pull system which means you produce to demand and do not produce to stock.

So, let us spend some time on each one of these. TQM - Total Quality Management, employee empowerment, 0 inventories and pull systems. Now, TQM stands for Total Quality Management, a quality are an extremely important aspect of manufacturing. Traditionally quality has had several definitions. The 2 important definitions, the traditional definitions are fitness for purpose and conformance to specifications. When quality is applied to manufacturing the traditional definition is conformance to specification. When quality is applied to service the traditional definition is fitness for purpose.

So, when there is a purpose for which a certain service is desired and if that service is fit for that purpose then we say that it has quality. Since we are talking about manufacturing systems, conformance to specification is an extremely important definition of quality. Every manufactured product has a certain specification. The ability of the manufacturing system at the end of the day, to conform to specification so that eventually the product is usable which indicates the amount of quality that comes into the product. Because conformance to specification was the traditional definition of quality, traditional ways of measuring quality was based on rejects where measurements were not confirmed.

Inspection to check whether there is conformance to specification and control of process whereby the process conforms to the specifications. Much later, definitions of quality changed. One of the important definitions of quality is the characteristic or the ability of an entity to meet the stated and implied needs of a customer. In manufacturing, many times the needs are stated in terms of product definitions, in terms of specifications. In service sometimes the requirement for service is stated, sometimes the requirement for service is implied.

Since we are in the context of manufacturing we would now try and define this suitably; the definition that the ability of an entity to meet the stated and implied needs of the customer; now if we go back to one of the early slides that we used in this lecture series where we described the requirements of manufacturing and there another slide on changing customer expectations. Now, the ability of the manufacturing system to meet the changing customer expectation or to meet the requirements of manufacturing indicates that a good quality manufacturing system will meet all the requirements of the customer which is in terms of providing new products, which is in terms of providing volume, which is in terms of providing variety, which is in terms of providing the products to the customer with short runs and no rejects full conformance to specifications and so on.

So, JIT is a way by which we use these ideas of total quality management, bring quality into the system and achieve less cost by pursuing waste reduction. Employee empowerment is another important aspect of JIT. Traditionally manufacturing systems were hierarchical in the sense that there is a shop floor. There will be shop floor managers, there will be supervisors and there will be operators. Now, in a JIT kind of an environment particularly within a cell the operator who works in the cell completely owns what is happening within the cell.

We have already seen that 2 important characteristic of Cellular Manufacturing is ownership and responsibility. In the earlier system when something went wrong, the operator has to go to the next level report and take actions. In a system that has just-in-time manufacturing or total quality management which allows employee empowerment. The operator or the employee is empowered to take decisions in the interest of the manufacturing system. So, this way JIT is a way by which we use TQM, employee empowerment, 0 inventories and pull systems.

We will look at some more aspects of 0 inventories and pull systems and some more concepts in just-in-time manufacturing in the next lecture.