Manufacturing Systems Management
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Lecture – 25
Single piece transportation

In this lecture we continue the discussion on cell scheduling and sequencing. We particularly look at the advantage of single piece transportation.

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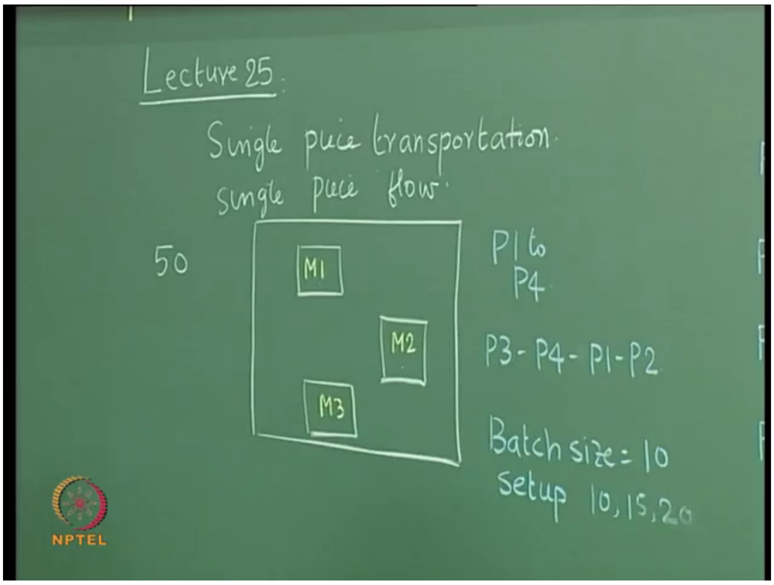

So, if we consider a cell which has 3 machines, which we could call M 1, M 2 and M 3 and if all the pieces visit all the machines the biggest advantage of the cell lies and the fact that these machines which are dissimilar are located close to each other. Since they are located to close to each other if we are processing a batch of 50 saying, it is not necessary that we have to transport from this machine to this machine after all the 50 pieces are completed, trans waiting for all the 50 pieces to be completed here and then transporting after the batch is over takes more time.

So, it is possible to transport them as and when the pieces are completed and this results in enormous saving in time compared to situations where these machines are far away. In a process layout or in a functional layout or a specification or a department specialized layout, these machines would be far away from each other and because they are far away from each other the transportation between the machines happens only after a certain number is completed. We will now see the advantage of what we call as single piece transportation and also link it up with what is called single piece flow. So, first we will look at single piece transportation using an example and the example is given in the slide.

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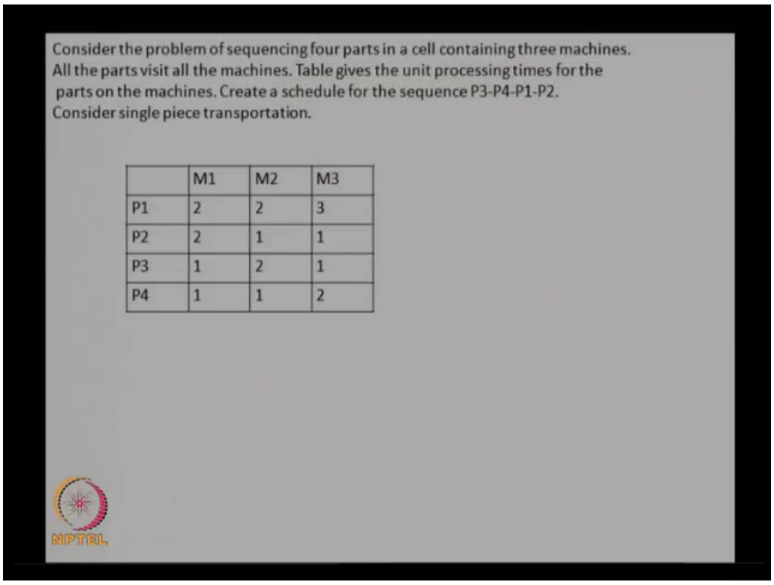

So, this cell makes 4 products which we can call P 1 to P 4. All the 4 products visit all the 3 machines and we are looking at a sequence P 3, P 4, P 1 and P 2, the sequences P 3, P 4, P 1 and P 2.

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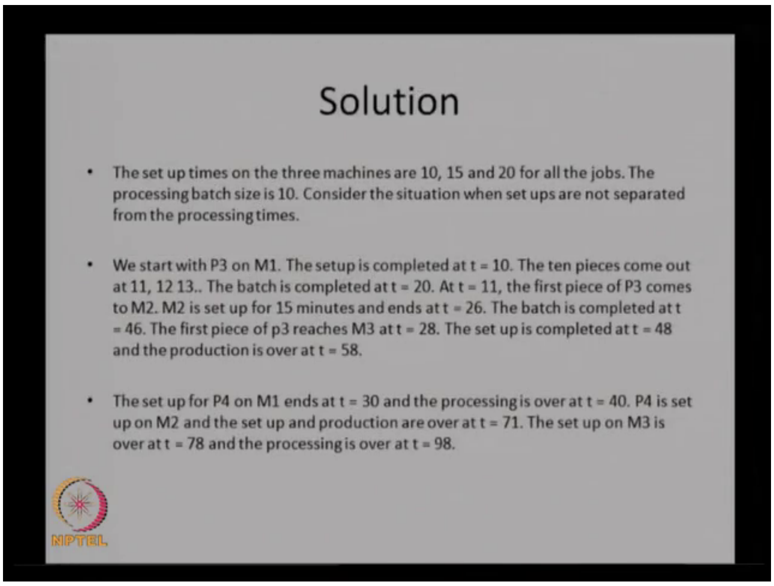

The unit processing times are given in the table the setup times are 10, 15 and 20 for all the jobs and the batch size is 10. So, we say batch sizes 10 and the setup times are 10, 15 and 20.

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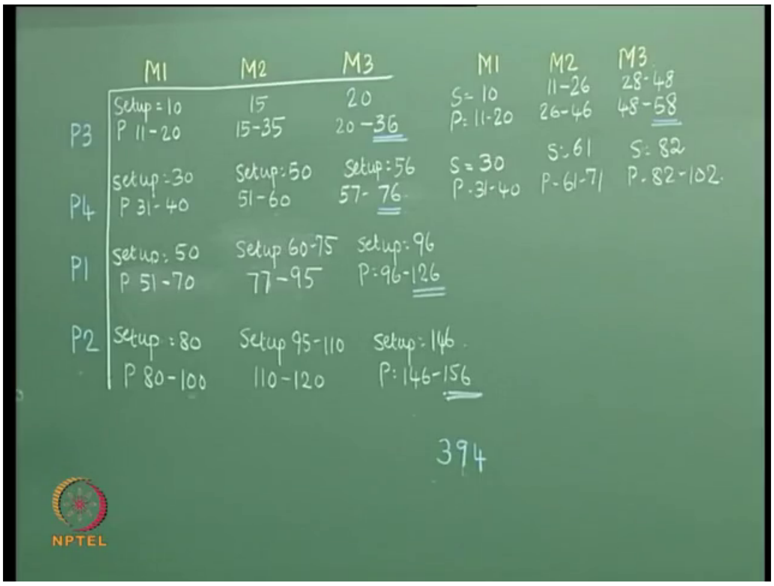

Now, let us draw the schedule for the sequence P 3, P 1, P 4 and P 2. So, we start with there are 3 machines M 1, M 2 and M 3 and the sequence is P 3, P 4, P 1 and P 2. Now at time equal to 0 all the 3 machines can now do the setup for P 3 which is the first product or part to be made, setup times are 10 15 and 20, so setup is completed at 10 at 15 and at 20. Now the batch size is 10 the unit processing time is to is 1 for P 3 on M 1. So, processing starts from 11 to it takes another batch sizes is 10 each is going to take 1 time unit. So, 11 to 20 the batch will be completed on M 1

Now at time equal to 15 M 2 is ready, so if we transport unit 1 as soon as the first piece is over, here if we transport here then the first piece can start at time equal to 15 it would take to time units. So, the processing will happen between 15 to another 20. So, to 15 to 35 the processing is over. Now the third machine finishes the setup at time equal to 20 and it is available at time equal to 20. So, here the times will be 15, 17, 19, 21, 23 etcetera. The first piece can start at 20 the time required is 1 time required is 1, so it can start at time equal to 22 the last piece will come out at time equal to 35 and the time there required is only 1. So, the last piece comes out at 35. So, the last piece will enter at 35 on M 3 and finish at time equal to 36 on M 3. So, at time equal to 36 P 3 will be over this is a solution where we show that at time available the machine actually starts its setup at time 0 the setup begins.

Another way of looking at it as shown here would be that the setup is completed at t equal to 10. So, 10 pieces will come at time equal to 20 another way to say is when the first piece comes out at time equal to 11 this is now set up and set up happens starts at 11 and finishes at 26 and then 10 pieces would come out between 26 to 46. The other way to say is at 48 the first one comes out here 26 now first piece starts at.

The other way to look at it which is what is shown here, here what we have done is we have assumed that at time equal to 0 since both these machines are free we can do the setup and wait for the pieces to come. In the solution that is shown there what we assume is as soon as the first piece arrives the setup begins. So, here what we do is when the setup is finished at 10 the first piece would arrive at 11. So, 11 plus 15 26 the setup ends and from 26 to 46 this processing happens the first piece would finish at 26 plus to 28. So, at 28 it will go here another 20 time units 48 and then the last piece will come out at 58.

So, this what is shown in bullet number 2 assumes that the setup begins only after the first piece arrives. Now what we have done here is we are separated the setup times from the processing times. So, setting up the sub separating the set up time from the processing time also gives us an additional advantage. Now when setup times are not separated from the processing times we would get that kind of a solution. So, let me just show that kind of that solution for only for P 3 when setup times are not separated from the processing times which means setup will begin once the batch arrives or once items start arriving.

So, that can be shown here as for M 1 for M 1, M 2 and M 3 setup starts and setup is over at time equal to 10, processing is over between 11 and 20, now the first piece comes at time equal to 11 setup takes another 15 time units, so 11 to 26 and processing will happen between 26 to 46. Now the first piece will come at 28. So, 28 to 48 and 48 to 58. So, when we do not separate the set up time the time taken to produce the batch is much more. The reason is these are going to be ideal between 0 to 11 and up to 28 time units this is going to be ideal here we are not having that we start the setup then there. So, we do not keep the machine ideal. So, we continue to work on this assumption rather than the other assumption because we want to finish the production as quickly as possible.

So, now, we go to the second product now this is over at time equal to 20. So, set up will be over at time equal to 30 because setup takes 10 time units on the first machine. So, setup is over at time equal to 30. P 4 takes 1 unit, so processing time will be 31 to 40. Now at 31 the first piece can come here, but it has to wait till 35 because this take. So, much time up to 35. So, setup can happen start only at 35 and finishes at 50. Now when setup finishes at 50 now the peace has come anytime from 31 32 up to 40 setup finishes at 50 time to produce is 1 time unit. So, 51 to 60 this is being done. Now again here the pieces start coming at 52 and so on, but this is over at 36, so it has to wait till 51 when the first piece comes. So, this has to wait till 51 when the first piece comes. So, setup will be will start at setup can actually start at 36 itself here because this is free at 36. So, setup will start at 36 and finish at 56.

The processing time is 2 units, so the last one is going to finish at 60 and it is going to come here at 60. So, production will finish at 62 and the first piece can come out setup is over at 56 time taken is 2 time units per piece. So, it will begin at 56 or 57 to 76, 76 is the time at which this will complete. Whereas, if we continue the other one now you see that the time will increase further. So, let us do this here the production is over at 20. So, setup will be over at 30 again and then the next production will be over at 40, here this is over at 46. So, we can actually begin the setup because the first piece would have come by that time.

So, setup will be over at 46 plus 15, 61, the time taken to produce is 1 so production will be 61 to 71. So, here the first piece will come at 62 this is over at 58, but the first piece will come at 62. So, setup will be 62 plus 2 82 and the production will happen this will start coming. So, production will be 82 to 102. So, you can see the difference between 76 here and 102 here.

Now the third one setup will begin at 40 and end at 50 processing will be between 51 to 60 because time to produce this 1 unit. Now here exactly at 60 the production is over. So, setup can begin only at 60 even though the first piece can come out at 1. So, setup will start at 60 and will be over at 75 at 75 we can start producing. So, the production will be between 75 to it takes 2 pieces 75 to 95. P 1 the time is 2, so there is still another small error here setup finishes at 50 P 1 on M 1 is to time units therefore, production will be 51 or 52 70 batch size is 10. So, it takes 2 more time units. So, here we can do the setup from 60 to 75 the first piece will come out at 52, so production will be will start at 52 again 2 units. So, 52 it begins to 75 plus 20 95. So, this is free at 76. So, setup will have start at 76 and finish at 96. The first piece will come out will start only at 96 it takes 3 time units. So, 96 plus 30 126, production equal to 96 126 by which time the last piece could have easily come out. So, there is no waiting. Takes 3 pieces 30 time units, so these things are going to come out at 75 to 95, this will become 77 to 95. So, these will come out at time 77 79 81 83 and so on. So, but they will begin at 96 99 102 like that the pieces will come out.

The last one set up time will start at 70 and be over at 80 production will be from 80 to P 2. So, 2 time units 80 to 100. So, here set up can start at 905. So, set up is 905 to 110 takes 1 unit of time. So, production is hundred and 10 to 120 by which time this would have come out. So, here again set up time is 126 plus 20 146, 1 unit, so processing time will be 146 to 156. So, at time equal to 156 all the 4 products can come out if we do what is called single piece transportation from this to this, if we do single piece transportation from this to this.

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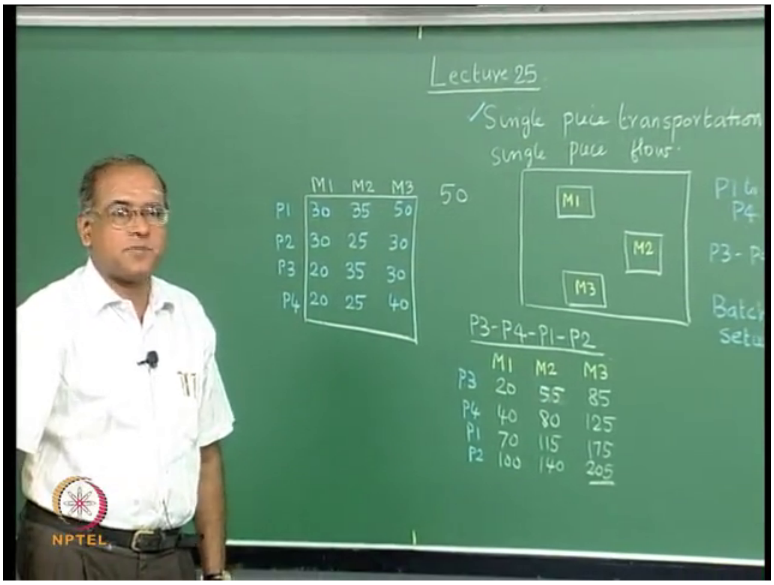

But if on the other hand we had followed a more traditional approach of computing the times then we would have a matrix which is like this with P 1 P 2 P 4, set up time is 10 batch size is 20, so the times would be 30, 30, set up time is 10 batch sizes on this the set up time is 15 15 plus 20 35; 20 plus 30 50; 20 comes from the set up time 10 in to 3 30, 3 is the processing time 50. Again 10 plus 20 30, 10 is the set up time to is the unit processing time 15 plus 10 25, 20 plus 10 30, 10 plus 10 20, 15 plus 20 35, 20 plus 10 30, 10 plus 10 20, 15 plus 10 25, 20 plus 20 40.

So, these would have been the processing times now for the same sequence P 3 P 4 P 1 P 2 for the same sequence P 3 P 4 P 1 P 2 on M 1 M 2 and M 3 P 2 now we begin with P 3. So, 20 plus 35 55 plus 30 85, P 4 is 20 plus 20 40, 55 plus 25 80, 60 plus 20 80, 85 plus 40 125, P 1 is 30 40 plus 30 70, 80 plus 35 115, 125 plus 50 175 and P 2 is 30 70 plus 30 100, 115 plus 25 140 and 175 plus 30 200 and would have been the make span as against 156 which is the make span. Now the reason this happened is because of what is called single piece transportation or unit transportation, now here we assume that the entire transportation is a batch transportation we wait for all the 10 pieces to be done and then we transport as a batch. And we also have added setup times into the processing times. Normally the total processing time that is given in any flow shop kind of a problem is the set up time plus unit processing time into the batch size.

Now, this batch size is called production batch size which is 10. Now here production batch size is 10 as soon as all the 10 pieces are done on the first machine they move to the second machine then the setup begins and production begins. Now here the production batch size is 10 transportation back size is also 10, here the production batch size is still ten, but the transportation batch size is 1 because units move from 1 because we have assumed here that the first piece will come at 11, but can start at 15 because setup is taking 15. So, here the setup does not wait for this entire thing to be over; that means, start of the transportation does start of the production does not wait for the end of the production here the first piece which still would have started at time equal to 15 then in the same batch something is happening in M 1 also. So, this is the advantage of what is called single piece transportation that we have seen of single piece transportation that we see.

Now, if we know that now this kind of a system would have worked when we do not have the machines close to each other. The fact that the machines are located close to each other helps us in moving to this otherwise we would have done something like this when the machines are away from each other or even in a flow shop assumption this is what we would have done, but this we can do in a cellular manufacturing context.

Now, suppose we have to produce 10 units let us now start discussing with this. Now if we have to produce 10 of P 1 10 of P 2 10 of P 3 and 10 of P 4 and if we have this kind of a thing with unit transportation and set up times separated then we know that we can finish with time equal to 156 now suppose we have a little more time that the due date for this is not 156, but the due date is 200 now one way to do is to go back to this because this gives us about 205. But we could do one more thing here what we could do is here we said when we produce P 3 P 4 P 1 P 2 the production batch size was 10 transportation batch size was 1. Now, suppose we have a production batch size of 5 and transportation batch size of 1 let us see what happens?

So, let us do that somewhere here with production batch size of 5 and transportation batch size of 1.

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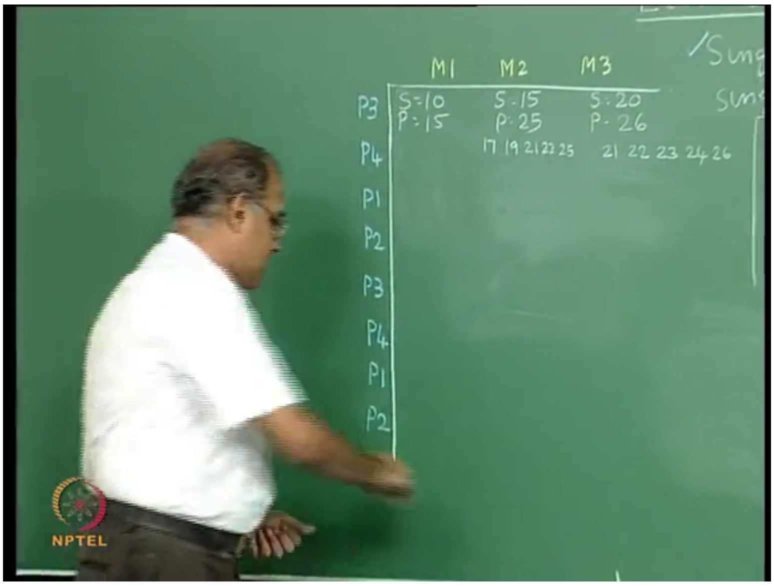

So, we will still have M 1, M 2 and M 3. So, we will now follow the same sequence P 3, P 4, P 1, P 2, P 3, P 4, P 1, P 2 because we will now have 2 batches of P 3 running because we have a production batch size of 5 and not 10. We will not have P 3 and P 3 running because P 3 and P 3 next to each other is equivalent of a production batch size of ten. So, let us work this out very quickly now here we start with P 3. So, set up time let me just write s equal to 10 setup is over at time equal to 10.

Now processing is over at time equal to 15, on M 2 setup is over at time equal to 15 the unit processing time is 2. So, processing will begin at time equal to 15 and end at time equal to 25 because batch size is 2. Now here the setup will be over at time equal to 20. So, processing can begin at the first piece would come at 17, but it can begin only at 20 and the time is 1, so this will be over at time equal to 26 because the last piece will come out at time equal to 25 and then it would get into this and then the time that the last piece comes out will be 26.

Here if we see carefully the pieces will come out at 17 19 21 23 and 25 they will come out at 17 19 21 23 and 25 they will be completed here at setup will be over at 20. So, the first piece will be over at 21, second piece would have come at 19 in it be over at 22, the third piece would have come at 21 it will be over at 23, the 4th piece comes at 23 it will be over at 24, the first piece comes only at 25 this is ideal. So, this will be over at 26.

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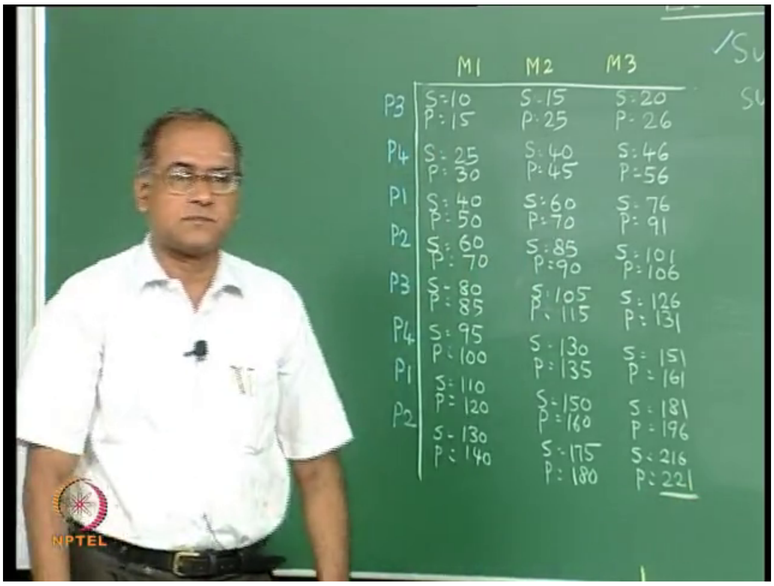

So, the time at which it completes is 26. So, we now move to this one were set up is over at 25 15 plus 10 on P 4 the unit processing time is one. So, production is over at 35 into 1 is 5 which is 30.

Now here setup is over at 40 25 plus 15 P 4 unit processing time is 1 there 4 processing is over at 45 now here the setup is over at 26 this is free. So, setup is over at 46 the unit processing time is 2. So, processing time will be the last piece would have come out at 45, but it can begin only at 46. So, 46 plus 10 56 it will be over. Now on P 1 4 P 1 setup will be equal to 40 10 time units of setup, now processing will be over at P 1 unit processing time is 2, so it will be over at 50. Now here production is over at 45. So, it can start the setup and setup finishes at 16. Once again on P 1 unit processing time is 2, so processing will be over by 70.

Now here again setup will be over at 76 the last piece would have come out at 70 unit processing time is 3, so 15, P will be equal to 91. Now we go back to P 2. So, setup will be over at 60 and P 2 unit processing time is 2. So, production is over at 70. So, here setup will be over at 85 because this production is over at 70 15 time units for setup. Unit processing time is again 1, so this will be over at 90. So, once again set up here will be over at 101 and unit processing time is 1, so processing time will be 106 now the first cycle of 5 is over now we look at the second cycle of 5.

So, second cycle of 5 P 3 again setup will be 70 plus 10 80 processing time will be P 3 on M 1 is 1. So, this will be over at 85. So, once again set up here is 105 processing time is 2 unit processing time, plus another 10, so 115. Here setup will be over at 106 plus 20 which is 126 processing unit processing time is 1. So, this will be over at 31 now we go to P 4 this is production is over at 85, setup is over at 95 processing P 4 unit processing time is 1. So, this will be over at 100.

So, here setup will be over at 130 because 115 it is over plus another 15 130 it is over, production unit processing time on P 4 is still 1, so 135. Now here setup is over at 151, 151, 131 plus 20 151. For P 4 unit processing time is 2, so this is over at 161. Now back to P 1 setup is over at 110 P 1 on M 1 unit processing time is 2. So, this is over at 120 now here production is over at 135. So, setup will be over at 150 P 1 on M 2 unit processing time is 2. So, production will be over at 160 setup will be over at 181 20 time units, unit processing time is 3 so production is over at 196. Now setup is over at 130 production will be over at P 2 unit processing time is 2. So, this will be over at 140. So, again here setup is over at 175 160 plus 15 unit processing time is 1, so this will be over at 180 setup is over at 216 unit processing time is 1, so 221 this will be over.

Now we look at 3 numbers that are a make span of 156 if we followed a production batch of 10 and a distribution batch of 1 or a transportation batch of 1 a make span of 205 that we had here the numbers that we had here when we followed this sequence P 3

P 4 P 1 P 2 and when we followed like a job shop, so P 3 on the last machine was 85 P 4 on the last machine is 125 P 1 is 175 and P 2 is 205, P 2 is 205.

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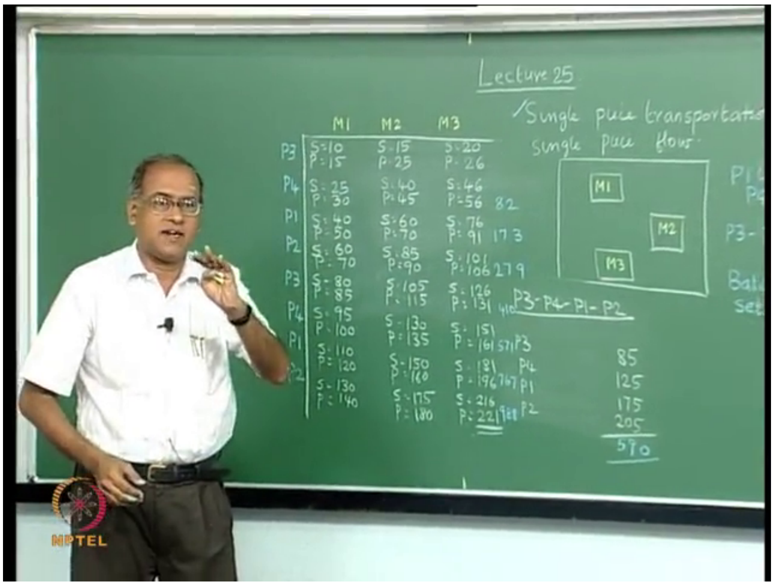

Now we look at these 3 numbers when we followed a flow shop like system we had these, but when we had the flow shop like system we used processing times that where for example, P 1 on M 1 was 10 which is set up time plus 2 into 10 20 which is processing time, so that was 10 plus 20 30. Like that we did with a production batch of 10. If we were to do a production batch of 5 then the time for production batch of 5 4 P 1 on M 1 would be a set up time of 10 plus a process in time of 10 which is 20. So, the time would have reduced because set up time remains the same for a production batch size of 5 the production time is half. So, it would have become 10 plus 10, but we have to do P 1 twice. So, that would be equivalent of introducing a P 5 P 6 P 7 P 8 where P 5 is the same as P 1 and so on.

So, it will become a 8 job 3 machine problem in a flow shop and when we do that the time would be well beyond 205. This will be higher than 205 in fact, it would be even higher than 221. So, this would still be economical compared to treating it in a flow shop mode and then treating P 1 has 2 jobs P 1 and P 5 each with a set up time of 10 and a processing time of 2 into 5. So, we need if we need to compare this and this realistically which we have done we can compare this and this also and then see what exactly has. We have already made the comparison between this and this and said that if we had followed the flow shop idea then 205 would have been the make span or the time spent in the system here 156 is your makespan.

Secondly, and more importantly more than the make span let us look at the amount of inventory lying in the system. The amount of inventory lying in the system is indirectly or represented by the sum of completion times which is a flow time. So, sum of completion times for this is 36 plus 76 plus 126 plus 156 which is 4, 19, 1, 3, 36 112 238, 394.

The sum of completion times here is to now you can see the amount of inventory that is lying in this system is far higher. So, on 2 counts this is not very desirable it has a higher make span of 205, if the due dates are lesser than that if the due date is 180 then this will give you tardy jobs and it has inventory about 590 minutes of inventory. This can complete everything by 156 and has an inventory of 394. Now why did we do this? If we did this then everything is completed at 221 which is poorer than 156 which is also understandable it will be poorer than 156, now if we start taking the sum of completion times let us see what happens. 26 plus 56 plus 91 plus 106 plus 131 plus 161 plus 196 plus 221 that is the sum of completion times. So, that will be 26 82 173 279 410 571 767 988. So, 988 is our sum of completion times and here it is 394 is the sum of completion times.

It is not a fair comparison because somewhere batches of tens are moving here whereas, fives are moving here. So, a very indirect comparison would be divided this by 2 and make a comparison there. That is not a very correct thing to do, but that is a very good approximation to do. If you do that still this is slightly poorer than this that comes because of the additional setup times that are involved and even during that set of times the items are present here. So, what is the advantage of doing this? Advantage of doing this comes from some interesting things while all 10 of P 3 can go at 36 all 10 of P 2 can go only at 156.

Now look at P 2 here at 106 5 of P 2 can go the other 5 of P 2 goes at 221. So, what we can do is we can now start if even if the demand is 10 for which the production batch size was made as 10 there and 2 fives here we deliver if we can deliver half of it quicker. So, the first batch of P 3 P 4 P 1 P 2 will; obviously, go sooner than 36 76 126 156 they would go at 26 56 91 and 106. The next batch of 4 would take a little longer the moment we start dispatching them if we actually start counting the inventories you will like you will realize that this is actually this is slightly better than the other one in terms of control. In terms of absolute numbers yes this would still show slightly higher value because of the additional setup time and all the items are present during the additional set of time, but in terms of control this will be better. This will be able to meet due dates well for half the batch.

So, if we can split it into smaller production batches we will be able to meet shorter due dates or we will be able to say that if instead of sending a full batch of 10 at 36 if it is advantageous to send this as at 26 and 131. More importantly instead of sending the full thing at 156 now we are looking at sending it at 106 and 221. Now this is called this an exact this is not single piece flow this is still a batch size of 5 and a unit transportation.

Now we can try and bring this batch size down when we had a demand of 10 we you we showed 2 cases with batch production batch size of 10 transportation batch size of 1, production batch size of 5 transportation batch size of 1, now as we keep reducing the production batch size of here these numbers will keep increasing because the set up time is not reducing. So, more the set up time the higher these numbers are going to come. So, if we do something to bring down the setup time instead of 10 15 20 if we do something to bring it down to say 5 10 and 10 then you realize that this number would come closer to the 356. So, when the setup times are smaller we will be able to have small run.

If we go back to the beginning of this course we said one of the requirements of manufacturing is to produce a variety with short runs. So, this enables producing a variety in short runs here also we produce a variety of 4 items, but here we are able to do it in 8 batches more batches in smaller runs. So, that the output can come out quickly and meet the requirements of the market.

So, a good scheduling algorithm under the cellular manufacturing idea will try to not only use a single piece transportation which naturally happens to the cellular manufacturing, but it would also try and bring down the back sighs to an ideal batch size of 1, a ideal situation would be I do 1 of P 3, if I am having a bad size of 10 the ideal situation is to have P 3 P 4 P 1 P 2 repeating 10 times with the production batch size of 1 and a transportation batch size of 1. Obviously, that is not easy to do because setup times are large. So, the focus on all of these is to bring down the setup times. Or when the setup times are small it is possible to have smaller or shorter runs, 1 may be difficult to achieve, but if we are able to achieve a 5 or a 10 production batch size instead of a 50 or a 100 then we have reaped the full benefits of this cellular manufacturing.

So, what are the things that we have actually seen in under the sequencing and scheduling? We have seen, let me explain this in the context of the various types of cellular manufacturing systems that we have actually seen. So, in cell formation we have seen 3 types of cell formation one which we could call as the machine cell part family formation, then we saw remainder cells and then we saw product based cell formation.

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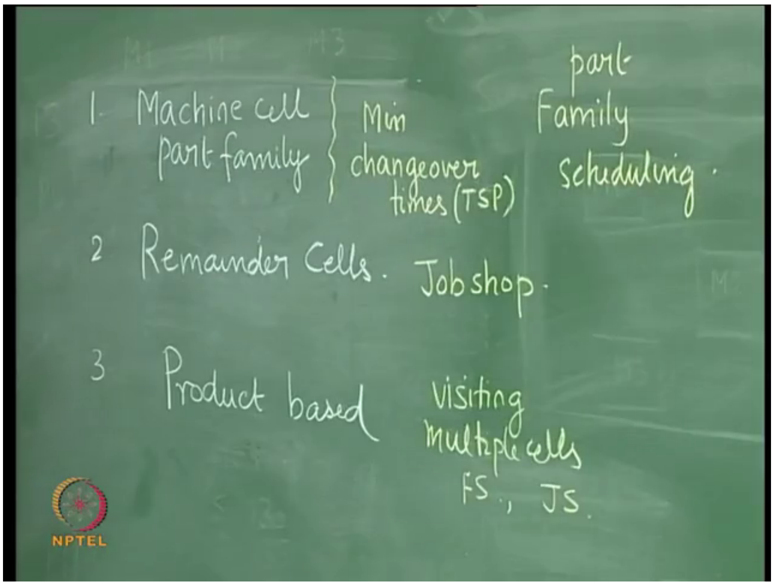

So, what are the kind of scheduling sequencing models that we saw? The first model that we saw in sequencing and scheduling was the changeover times and we modeled it as a traveling salesman problem. So, that can come here when we have minimized changeover times and solve a traveling salesman problem are a traveling salesman path problem.

The next thing that we saw was a flow shop kind of a situation where the part visits multiple cells so that kind of a thing can happen in product based situation, sovisiting multiple cells and sometimes these cells could even be very small nagare cells operated by single operator. So, the second model that we saw when it visited multiple cells was useful here in the context of product based. We also modified it and said it may skip a cell and then it would do the flow shop the job shop kind of a thing. So, this is closer to flow shop scheduling if it visits a cell we said we could use the job shop scheduling idea.

The job shop scheduling idea also comes under the remainder cells where we already said that in the remainder cell or a service cell we have a large number of machines that are there and the remainder cell functions like a job shop.

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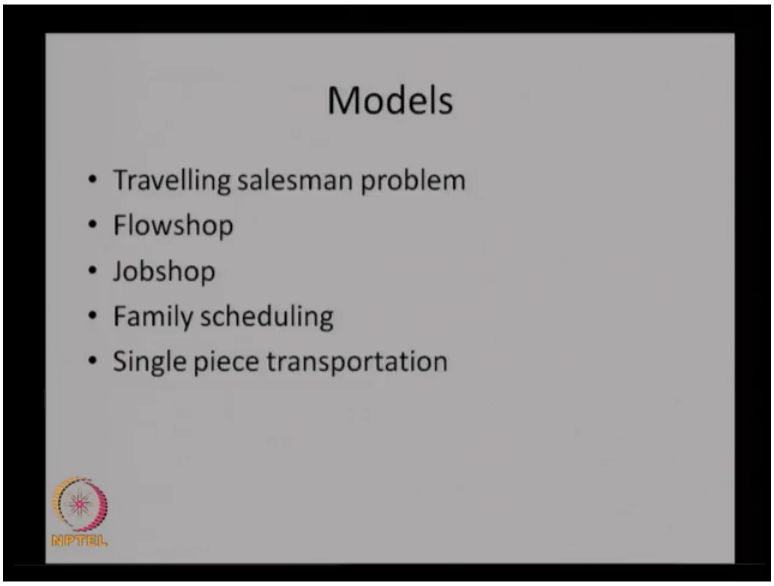

So, basic ideas from job shop scheduling now come to can be used in the context of you can the context of remainder cells. Then we also looked at part family scheduling where we said that the parts are divided into families, families are sequenced first and then parts are sequenced within the family. So, that can happen even here sometimes we can have that, so we could say family scheduling part family scheduling can happen here when a cell has more than one part family visiting.

Finally, we saw the advantages of single piece production and single piece transportation which can be applicable in the entire thing, but very largely applicable in the context of product based cells, single piece production and transportation, production and transportation.

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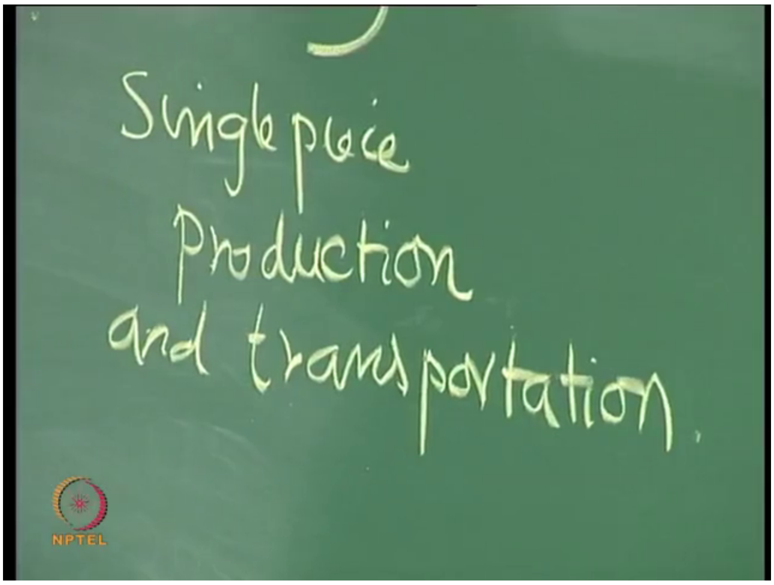

So, with this we complete the discussion on cell scheduling and sequencing. We will see some aspects of cell layout and then we move to sell control particularly using principles of just in time manufacturing. We will discuss these topics in the next lecture.