Production and Operation Management

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Lecture - 57

Manufacturing Operations Scheduling – II (Order Sequencing)

Welcome friends. So in our previous session, we started discussions about scheduling of operations. And this discussion is basically focused around process manufacturing, where we have job shop type of arrangement and in those job shops, we can produce variety of products and each product may have a different sequence of operations to be performed. And since, more and more orders are coming, each order maybe of different batch size and therefore the scheduling of operations is a very complex activity in a process category.

And therefore, we discussed that it is a very serious important exercise where we have various tools and techniques which decide that how to have the maximum productivity of your job shop. And there are different types of sequencing rules we discussed in our last session, that these are first come first serve, shortest processing time, than your critical ratio. And on the basis of some performance evaluating criteria, we see which particular sequencing rule is going to give you the best result.

And then we also need to see that the total change over cost and the total production time are also kept to lowest possible level. So, all these are the objectives of the scheduling exercise. And now in this particular session, we are going to see the scheduling activity with the help of some numerical examples. So, let us see a particular problem of sequencing and with the help of that problem we will see that how different criteria are used.

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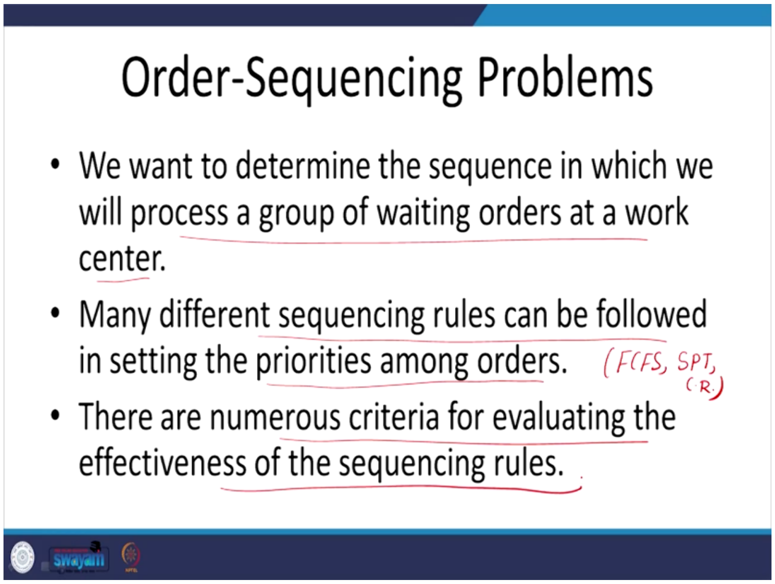

So now, we want to determine the sequence in which we will have process a group of orders at a work center. Now many different sequencing rules can be followed in setting the priorities among orders, and as I told this can be FCFS, First Come First Serve, it can be shortest processing time, it can be based on critical ratio, etc. And there are different criteria for evaluating the effectiveness of the sequencing rules. Now let us first see what are these different sequencing rules.

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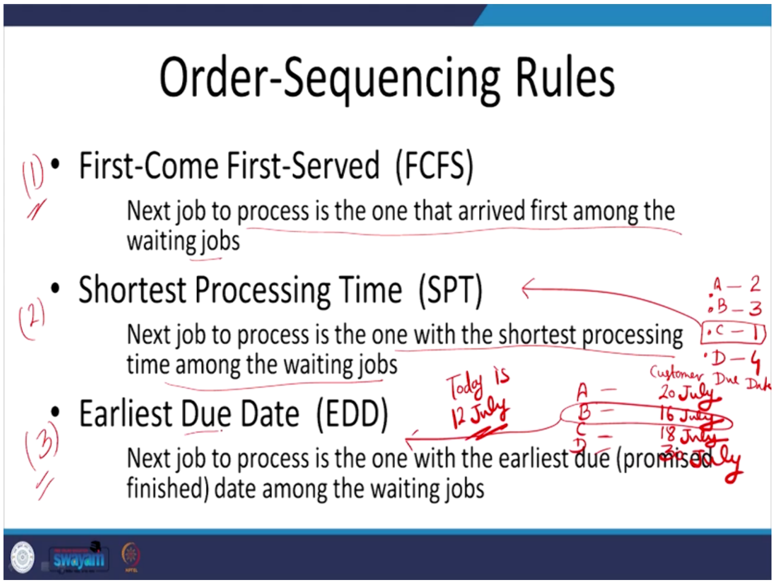

So, the first is which is, very simple to understand, first come first serve, FCFS that is normally it is called. So next job to process is the one that arrived first among the waiting jobs. So, as customers are coming to a particular place, they are served on the basis of their arrival pattern.

So, the jobs which are coming they will be served according to their arrivals. Then the second case can be the shortest processing time. Now the next job which is going to be processed is the one with the shortest processing time among the waiting jobs. There are 4 jobs, A, B, C, D. Now they have the different processing time requirement. It takes 2 minutes, it takes 3 minutes, it takes 1 minute, it takes 4 minutes. So, the next job to be processed will be the job C first, because it is the shortest processing time.

So, that is another way of deciding the sequence of operations. The third is earliest due date. 4 jobs are there, 4 orders are there; A, B, C, D. The customer due date, when customer is requiring. Today is twelfth July, now customer requires job A on 20th July, some other customer requires job B on sixteenth July, the order C is required to be dispatched on eighteenth July, and order D is to be dispatched on thirtieth July, these are there due date when the customers are expecting them.

So, you will now process this job B first because the due date is coming first for this particular job. So that is based on earliest due date. So, the job which is having the nearest delivery date that will be processed first and accordingly you will decide the sequence.

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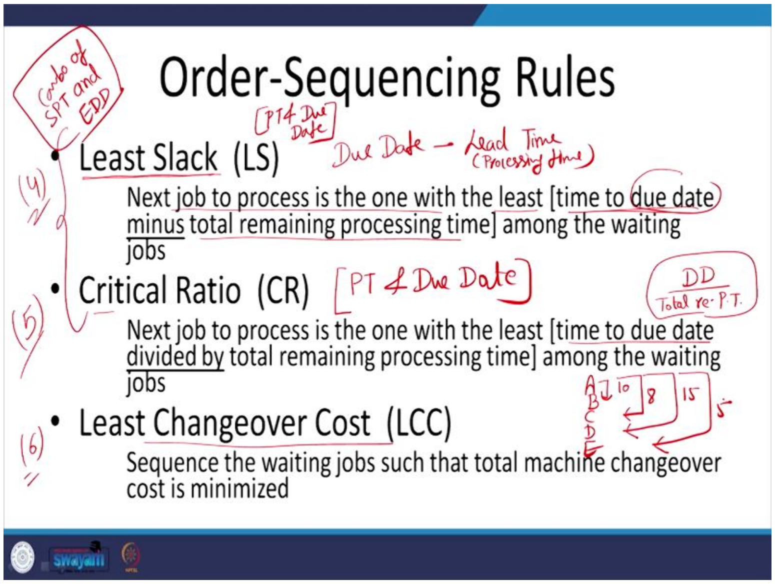

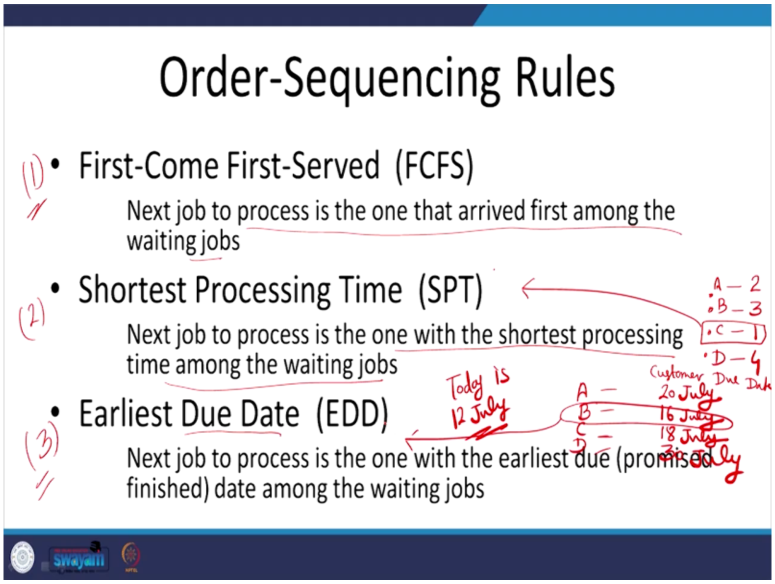

Then you have another rule like, least slack. Least slack is the next job to process is the one with the least slack that is time to due date minus total remaining processing time, that we discussed these two cases SPT and EDD. So, it is possible that this job which is requiring, which is required to be dispatched on sixteenth July takes only 1 day to process, it takes only 1 day to process. But job which is required to be delivered on eighteenth July it takes 4 days to process.

So now, it is advisable to combine the system of SPT and EDD, that how we can develop a rule where we can take the advantage of shortest processing time and earliest due date time and that is being combined in the form of least slack and critical ratio. Both these systems combine actually, combo of SPT and EDD both these systems. In one least slack, we are taking the difference between the due date, that is our due date, so this is due date minus lead time, lead time aur bracket mein you can write processing time.

So, due date minus processing time gives you the slack and the job which has the minimum slack will become your priority number 1. The second is, which is again the combination of shortest processing time, not shortest processing time it is more appropriate to say that it is a combination of processing time and due date. That is more appropriate to say, that these are the combinations of processing time and due date, so that we can take the advantage of SPT and EDD rules.

Now in this case, we take the ratio of processing time and due date. So, time to due date that is due date and divided by total remaining processing time, total remaining processing time, so this is known as critical ratio. And then, you select that job as your priority job for which the critical ratio is the minimum. And then another sequencing rule can be, least changeover cost where we are changing jobs from A to B, B to C like we have 5 jobs, as I just discussed A, B, C, D, E. Now when you are changing from A to B, the cost is 10 rupees.

When you are changing from A to C, cost maybe 8 rupees. When you are changing from A to D, cost maybe 15 rupees. When you are changing from A to E, cost maybe 5 rupees. So, once you are change jobs, from one job to another job, if you are in a glass factory, if you are in a glass factory and you are making black glasses, your glasses are black paint. And after black paint, you want to make glasses which are completely white, it is going to incur huge changeover cost. After such a dark color you want to produce a very light color, it is going to incur a huge cost.

So, we have a proper sequencing system that how to reduce the intensity of color so that you do not incur huge changeover cost. You can have very low changeover cost from white to black, but from black to white it is going to have a huge changeover cost. So, you should know that by following a particular sequence your changeover cost should not shoot up too much. So, that is also a very important issue in this sequencing decisions. Then, once we have these different types of sequencing rules, 6 rules we discussed.

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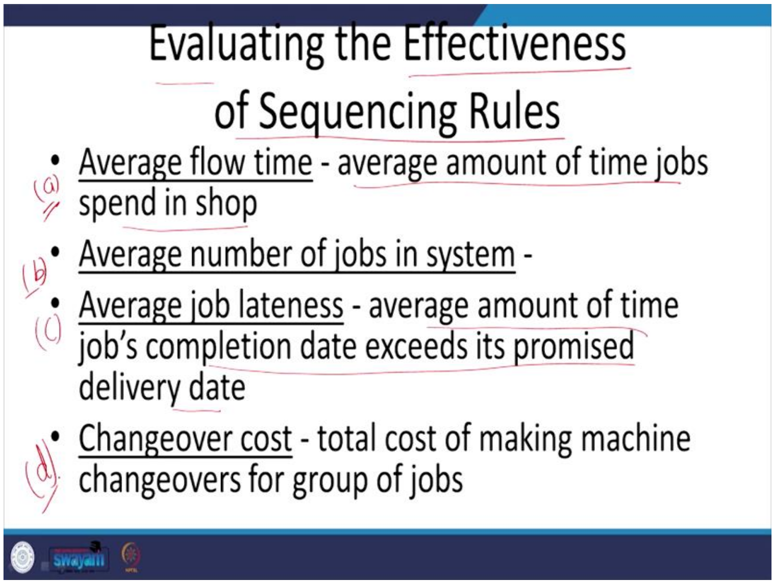

Now the second important thing in this case is the effectiveness of these rules. So, how to evaluate the effectiveness of these rules, the criteria on the basis of which we are going to compare these different rules. Now, there are four important parameters, four important you can say dashboard items which we are going to evaluate. And these dashboard items are, first is average flow time. Now the average flow time is a very important terminology we all must know, that is the average amount of time jobs spend in the shop.

That when a job is entering into the workplace, job shop and when the job is coming out of the work place. So, the entire duration for which the job is inside the work place, that is known as average flow time. So obviously, it is very simple to understand for any job we want to have this average flow time as low as possible. It means, you will have less amount of WIP in your system. If your flow time is more that means job is for longer duration in your work place and that will increase automatically your work in process inventories.

The second is, average number of jobs in system. At any particular time, how many number of jobs are there in the system. So that is based on the capacity of your system that how many jobs your system can handle at a particular time. Then another rule is average job lateness. There is a particular due date we already knew, that for each job customer has given us some target dates or we promised a particular date of delivery for a particular job.

Now, it is possible that some of the jobs are delivered on time but some of the jobs maybe delayed also. So, you calculate the average lateness from your system. So average job lateness is the average amount of time job's completion date exceeds its promised delivery date. So, what is your average job lateness, that also it is simple to understand that we want as minimum lateness as possible. If it is 0, that is the most ideal case that there is no delay from your system.

So, that is a very important criteria for evaluating the performance of the system that our average job lateness is 0. Most of the airlines they measure their productivity on this basis, that the average delay in the flights are 5 minutes, 10 minutes, 20 minutes and based on that we give the quality certifications to the airlines that these airlines are able to maintain their system with very high level of efficiency. Then another important criteria is changeover cost, the total cost of making machine changeovers for group of jobs.

As multiple jobs are to be made on a particular machine A, B, C, D, E etc. these different jobs you are going to make on the same machine one after another. So, what is the total changeover cost, so if you have a right sequence then you can minimize the changeover cost also. So, these are the different criteria and on the basis of various sequencing rule we calculate these costs and which particular sequencing rule gives us minimum cost for that particular scenario, that particular job shop, that sequencing rule must be followed.

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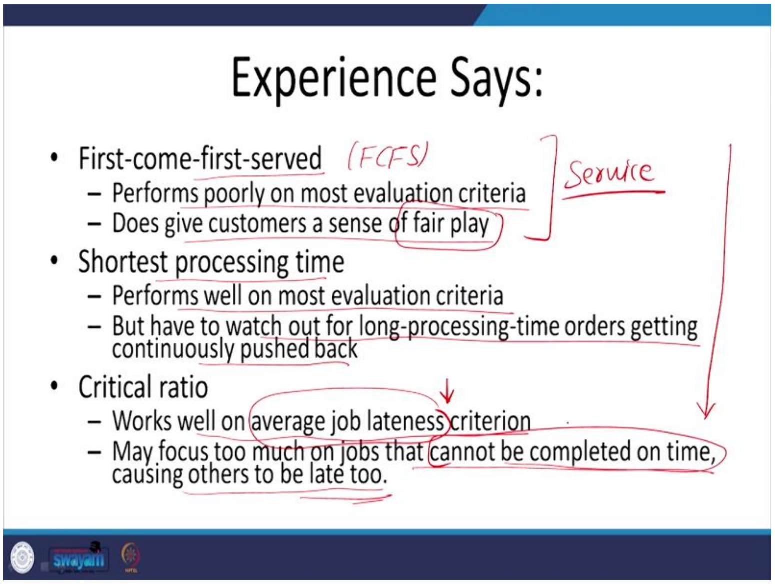

Now based on our researches, based on the field experience, normally there are some rules or some of the observations which are worth sharing at this time, that first come first serve rule, FCFS this performs poorly on most evaluation criteria. You do not get good results of FCFS and does give customers a sense of fair play but there is an issue with respect to that.

Though, from my point of view if I am the organization it is going to have low indicators for various performance criteria but from the customer's point of view, from your point of view you feel that you are fairly treated. You came to this system in queue at this particular time and there is a proper queue discipline and according to that queue discipline you are being served. So, as we go to the airport for boarding passes, as we go to the airport for security checks, as we go for various services this type of FCFS system is being followed.

At that time if a person who is ahead of me in the queue and that person is carrying lot of luggage and there maybe some issues with the ticketing of that person, I am going alone without any baggage but still, so my processing time is maybe in few seconds, his processing time is in few minutes maybe 20, 30 minutes but still because of that FCFS system it is being served first and I will be served later on. So, because of fair play kind of perception most of the service cases are being done on the basis of FCFS.

So, this is normally done in service cases where again the process focused manufacturing is taking place. Shortest processing time with respect to that, it performs well on many evaluation criteria. So, you have fairly descent performance indicators for SPT but have to watch out for long processing time orders getting continuously pushed back. But you will see that, if some order where more processing is to be done that will be continuously behind those items.

So, the chances of delaying that order, if the processing time for some order is very high, in that case that order will always be pushed back. And as a result of that, it may be severely delayed because of this SPT rule.

Then critical ratio, you see as we are moving from FCFS to this SPT, and then to critical ratio you will see that various parameters will start improving. It works well on average job lateness criteria. So, it is going to help you in reducing your average lateness because it is combining both EDD and this processing time, so it is going to reduce the average lateness. So, most of the jobs will be delivered with due dates.

So therefore, your average job lateness will be low in this case. Many may focus too much on jobs that cannot be completed on time causing others to be late too. Because it is combining due date and processing time, so it may, and due to that sometime it may focus on too much on those jobs which cannot be completed on time. So, those jobs which cannot be completed on time but because of this critical ratio issue, they may come into the processing and it may help, it may actually result into the delaying of other jobs also. So, that is a you can say drawback or limitation of the critical ratio issue.

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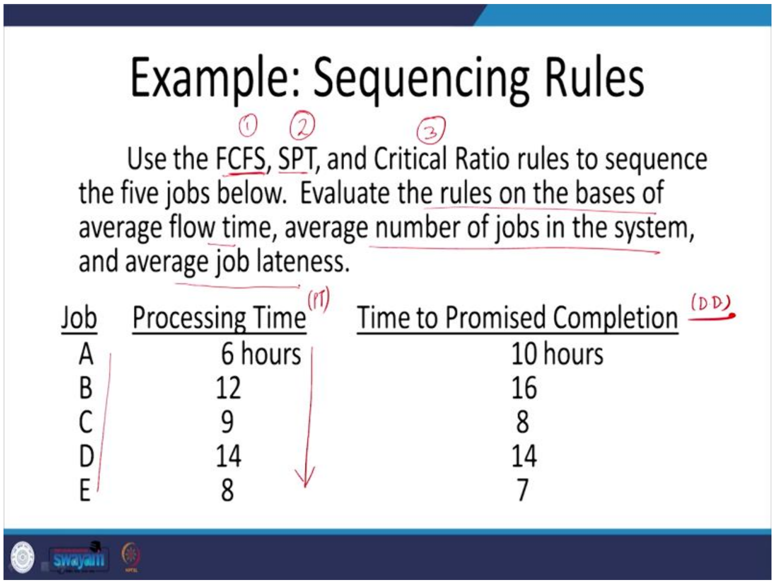

Now, let us have one example and with the help of this example we see that how different rules are applied. Now we want to apply these three rules FCFS, SPT, this is one sequencing rule, this is another sequencing rule, and this is another sequencing rule. To sequence the five jobs A, B, C, D, E these are the jobs. These are their processing time, PT's, and these are due dates. Evaluate the rules on the basis of average flow time, average number of jobs in the system, and average job lateness. So, let us start calculation for each rule separately.

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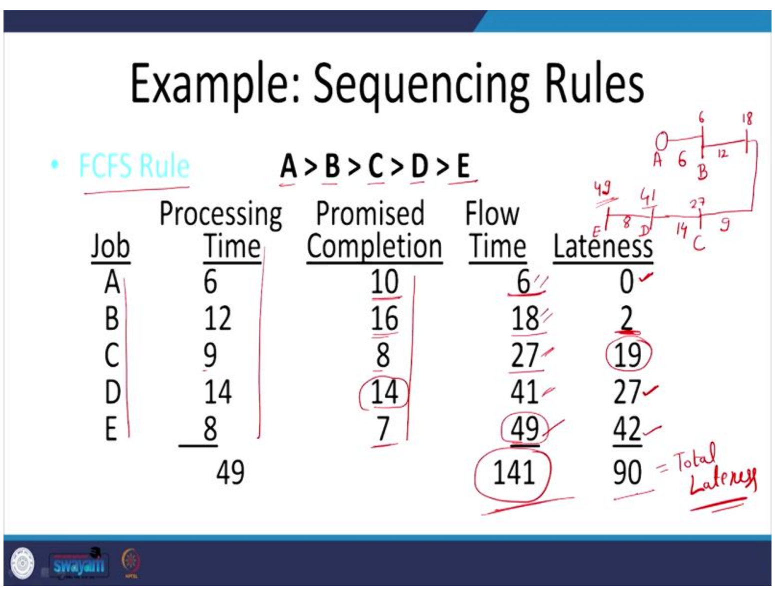

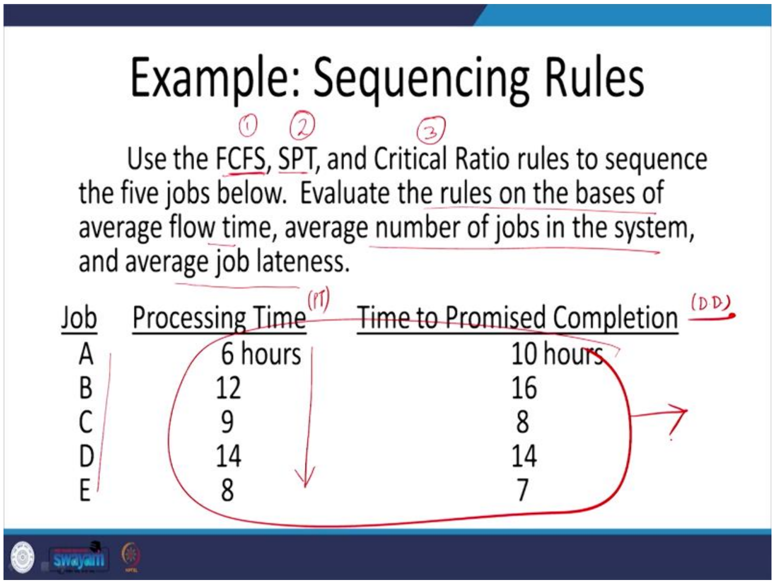

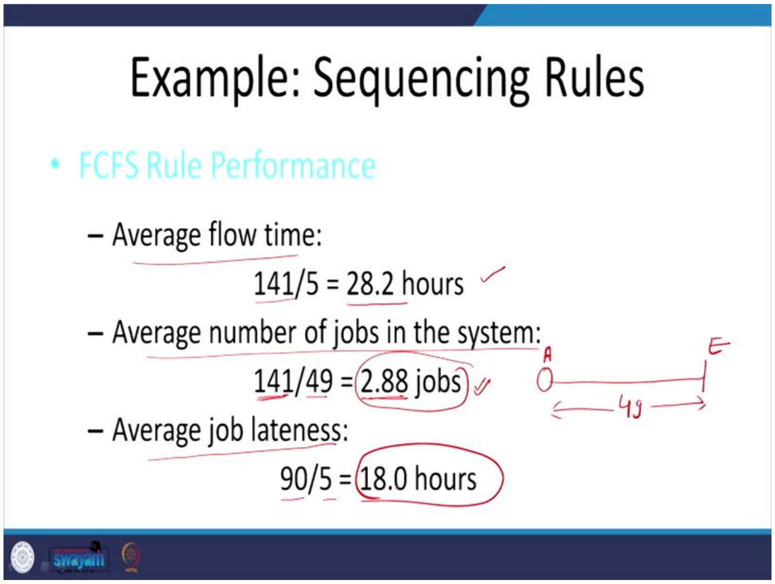

First, we are going to do for FCFS, First Come First Serve. So, we assume that they are coming as per their sequence, A, B, C, D, E. So, A will be first, then B, then C, then D, then E. The processing times are mentioned. The promised completion time is also mentioned. So, that data we have taken directly from here.

So, we have directly taken this data to the calculation of FCFS, 6, 12, 9, 14, 8 and the promised completion dates hours are also mentioned. Now, because this is the sequence of operation also so you see that this job A is entering into the system, job A is entering here and it is taking 6 hours. So, 6 hours it is coming out of the system. The promised time is tenth hour and it is already available at the sixth hour, so the lateness is 0.

Then B starts and B is taking 12, so finally, it is 6, it is 18. So, it is coming out of the system on the eighteenth but the promised time of the delivery is sixteenth hour. So, it is delayed by 2 hours, it is delayed by 2 hours. Then the third C, C has the processing time of 9. So, 18 plus 9 27, C. And the due date, due time was 8, so 27 minus 8, it is delayed by 19 hours. Then D will be there, it takes 14. So, it will take 14 and that makes 41 and D will come out. And D was expected to be delivered on fourteenth but you are delivering D on 41, so it is delayed by 27 hours.

And then finally, E will enter, it is taking 8 hours. So, it will be out on the forty ninth hour and it is E. E was expected to be delivered on seventh hour, but E is coming on forty ninth hour, so E is delayed by 42 hours. So now, you understand it is having a flow time of 6, 18, 27, 41 and this is coming out of forty ninth. So, the total flow time is 141. These are late by respective units, see total late, total lateness.

Now, with this data we can calculate the various performance indicators. The average flow time, total flow time which system is taking is 141 hours, total flow time which system is taking is 141 hours, so the, and these are the five jobs A, B, C, D, E. So, average flow time is 141 divided by 5, that is 28.2 hours. The average number of jobs in the system in that 141, you have the flow time for different jobs that is the maximum time is the forty ninth.

So, average number of jobs are 141 divided by 49, 2.88 jobs. So, at any particular time out of, because from 0 to job A is there and on this is the total, 49 and here E is coming out of the system. So, the meaning is that at any particular time in this system, at any particular time in this system 2.88 jobs are in the system. At any particular time when you are seeing the system, system has 2.88 jobs and these jobs maybe at different stages of their processing.

Some are starting the processing, some are at intermediate stage, and some maybe at the final stage. So, that is 2.88 jobs, that is another performance indicating criteria for us. And the average job lateness, the total lateness was 90 minutes, 90 hours and 5 jobs are there. So, 90 by 5, 18 hours that is the average job lateness. So, we got with respect to FCFS, the value of all these 3 criteria.

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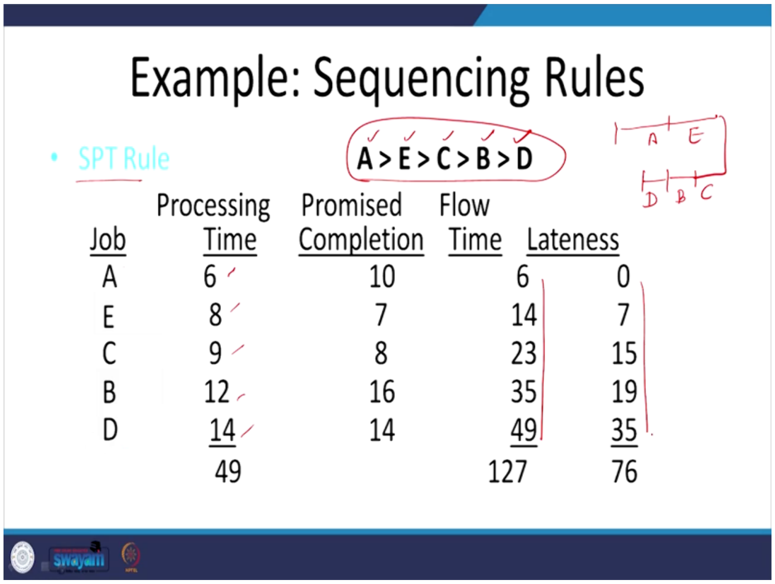

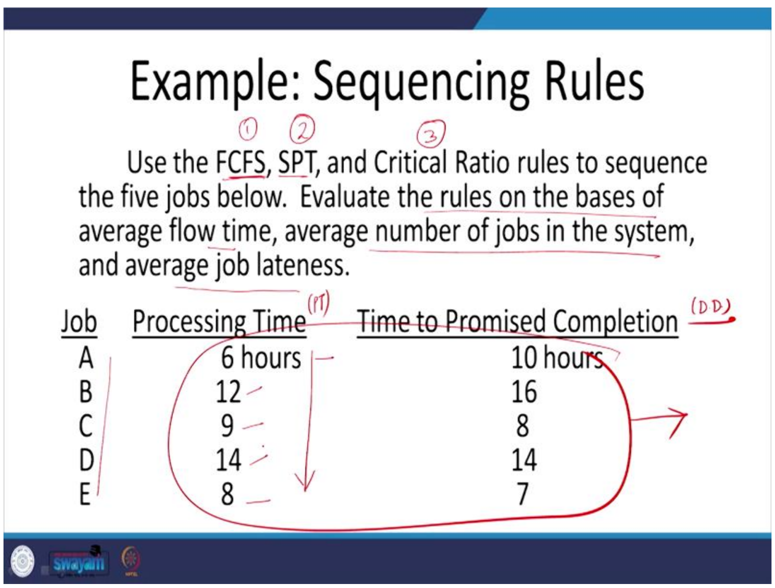

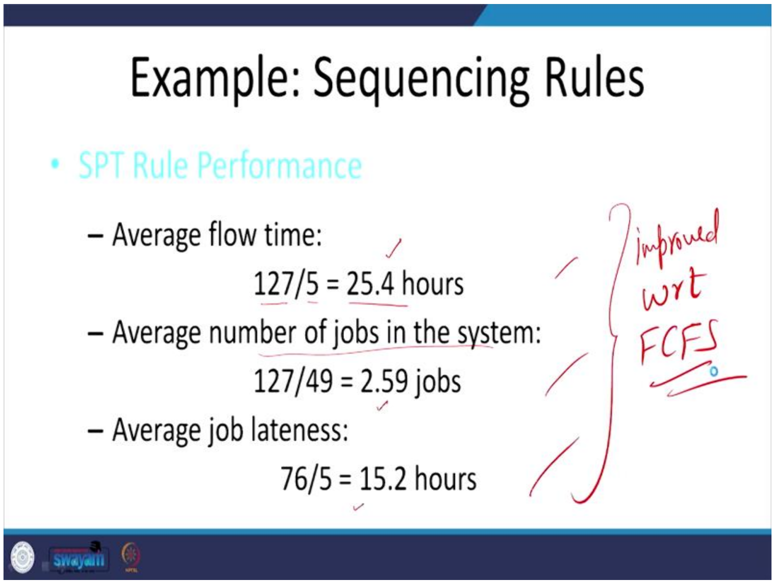

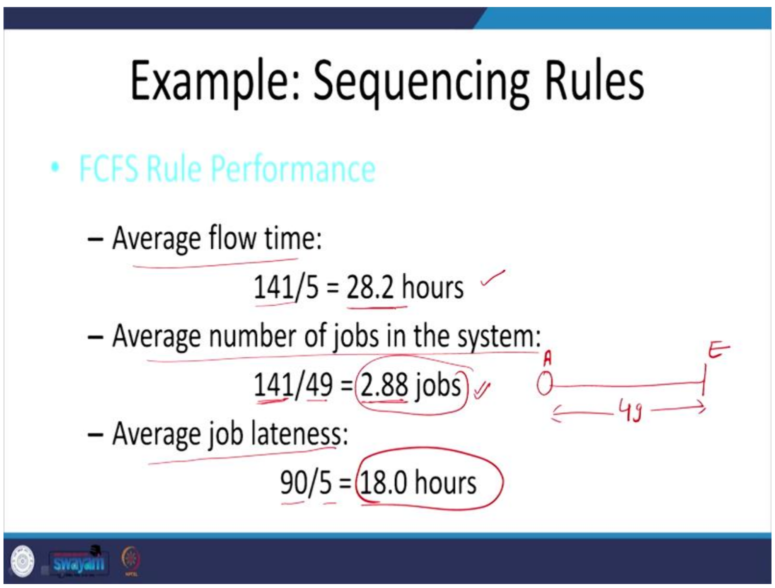

Now, we go with the shortest processing time. That is the another criteria, another you can say sequencing rule. So, A, B, C, D, E are there. Now 6, 8, 9, 12, 14 these are the processing time. Now we have arranged them. It is a matter of chance that we will produce them on the basis of this processing time. So, you just see that these are, first job is A, then E, then C, then B, and then D. So, A, E you remember A, E, C, B, D. A, E, C, B, D, so that is how you are going to produce. So, this is A, E, C, B, and D, these will be the sequence of jobs which we are going to produce and their processing times are written 6 hours, 8 hours, 9, 12, and 14.

And now, doing the same calculation that first job A will enter, then E, then C, then B, and then D. And here you again calculated the flow time for each of them. Now you also calculated similarly, as we did for FCFS the lateness. And now you see, the average flow time is 127 by 5 that is 25.4. You compare it with your FCFS, it was 28.2, now it has reduced to 25.4.

The average number of jobs in the system it was 2.88 earlier, now it has reduced to 2.59. The average lateness was earlier 18 hours, now it has reduced to 15.2 hours. So, all these 3 parameters have improved, improved with respect to FCFS, all these 3 parameters have improved.

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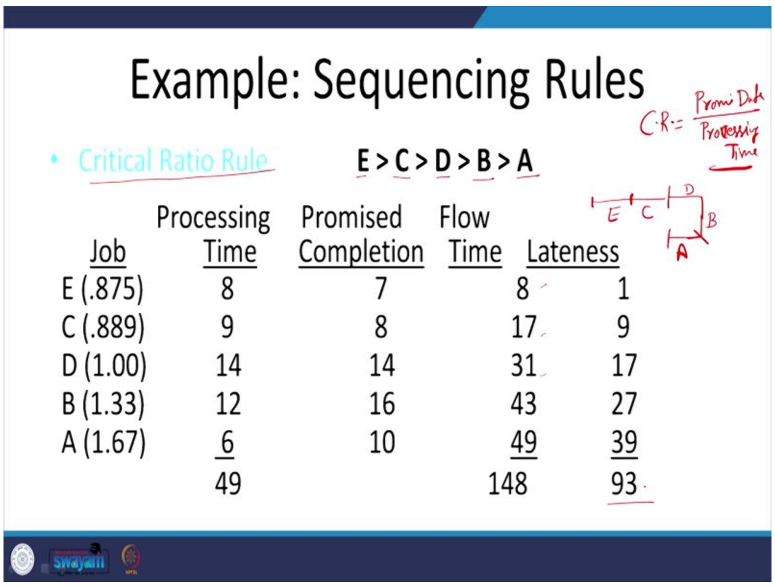

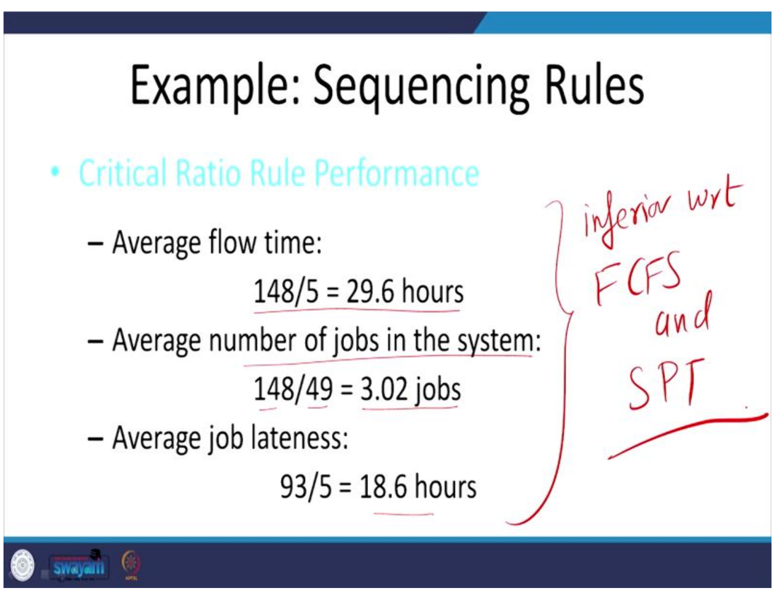

Now, we go to the third type of calculation, that is critical ratio rule. So, you calculate the critical ratio for all the activities. Now there are A, B, C, D, E, five jobs. The processing times are available to us and promised dates are also available to us. So, promised date that is due date divided by processing time, that is your critical ratio.

So, Critical Ratio, CR equals to promised date divided by available processing time. So, 7 divided by 8, it is 0.875, 8 divided by 9 0.889, 14 divided by 14, 16 divided 12 1.33 and 10 divided by 6 1.67. Now, whichever critical ratio is lowest, so now in the case for E this is the lowest. So, E will be processed first, then C, then D, then B, then A. So based on their critical ratio, you are going to process. And then you see that what is the flow time, that is again in the same way it is E which will be processed first, after E it will be C, then it will be D, after that it will be B, and then it will be A.

So, that is how you are going to process your various jobs in a this sequence. And similarly, you will calculate the flow time and the lateness for each of these jobs. So, the parameters 148 by 5 that is 29.6. So, for SPT it was around 25 but now it has increased. Average number of jobs in the system 148 divided by 49 that is 3.02 jobs, that is also increased. And average job lateness that is now is coming 93, so 93 by 5. So, that has also increased. So, now these are the inferior with respect to FCFS and even SPT. Now, you can understand that out of three sequencing rules, SPT gave us best performance.

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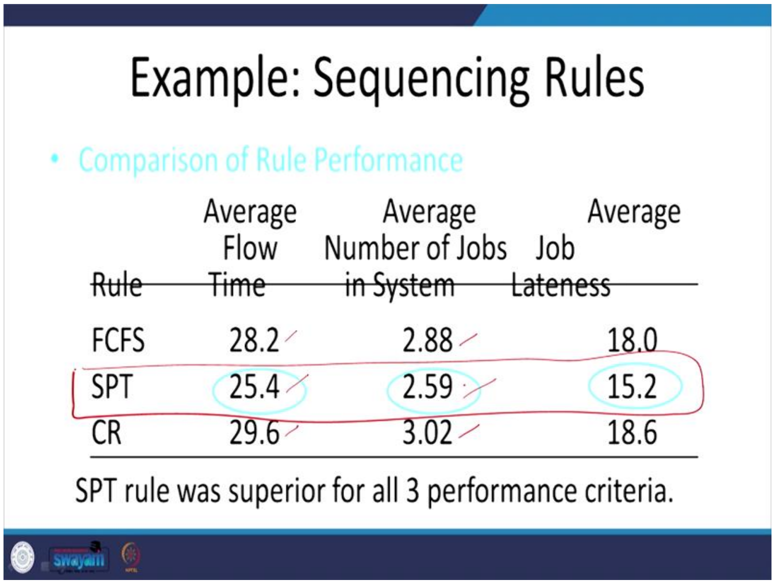

And therefore, for this particular example we are going to select the SPT rule as our sequencing criteria. So, here we have summarised all these three things in a particular tabular form, so you see that average flow time is 28.2 hours, 25.4 hours, and 29.6 hours. Average number of jobs 2.88, 2.59, and 3.02, that is also again better. And average job lateness 18 hours, 15.2 hours, and 18.6. So overall, with respect to all three criteria our SPT has resulted in a superior performance. So, SPT rule is better with respect to all three cases and that is going to be the sequencing rule for this particular example.

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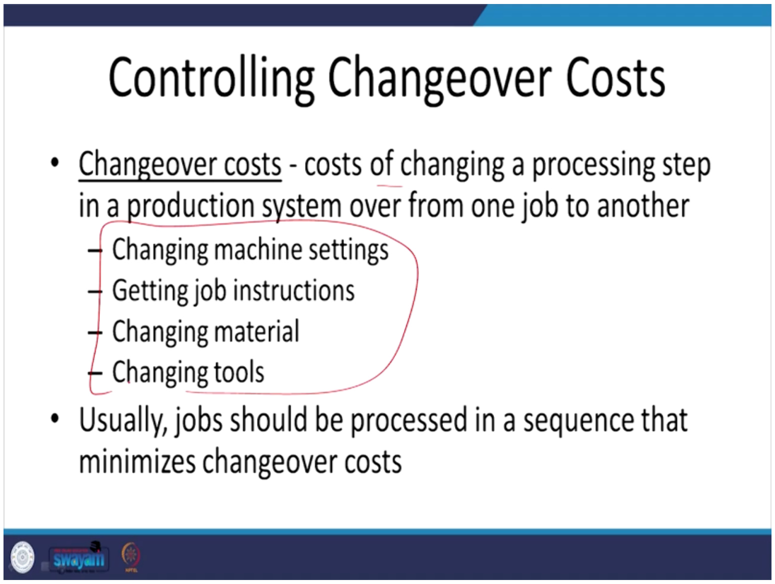

Now, the other particular issue is with respect to changeover costs. So, changeover costs is associated that changing the machine settings, and getting the new job instructions, the changing the working material, the raw material, or changing the tools.

So, all these things are required which are to be done whenever there is a change of the job and all these things actually incur some type of cost. So, you need to see that how this changeover should be done, so that your overall cost should be as low as possible. So, for that purpose, we have some kind of heuristics. So, heuristics you understand that we do not have any kind of mathematical proof for them but based on our experience, based on some, you can say established conventions these are considered to give you the lowest possible changeover cost in this particular case.

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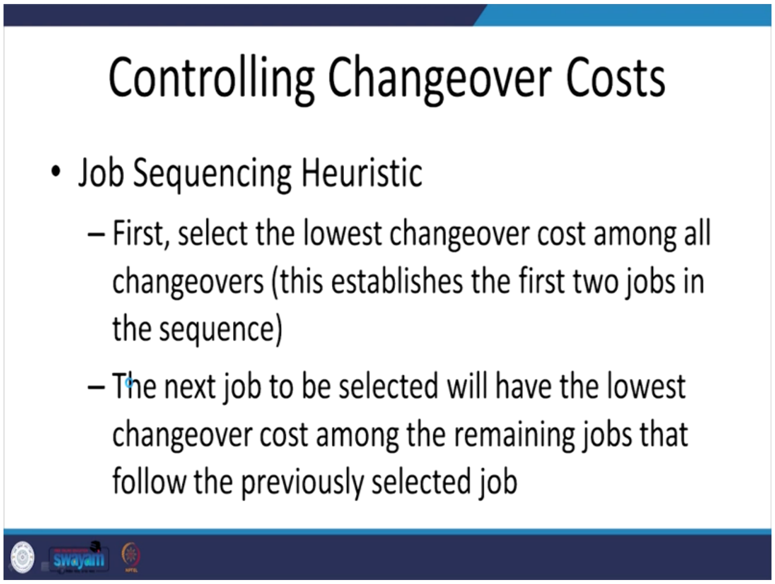

So here, we start with the lowest changeover cost, from one job to another job and in that sequence, we keep changing the jobs.

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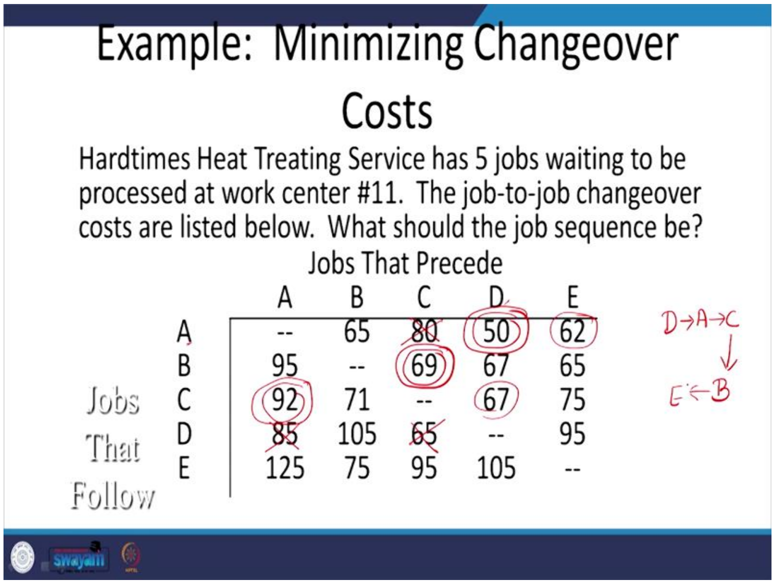
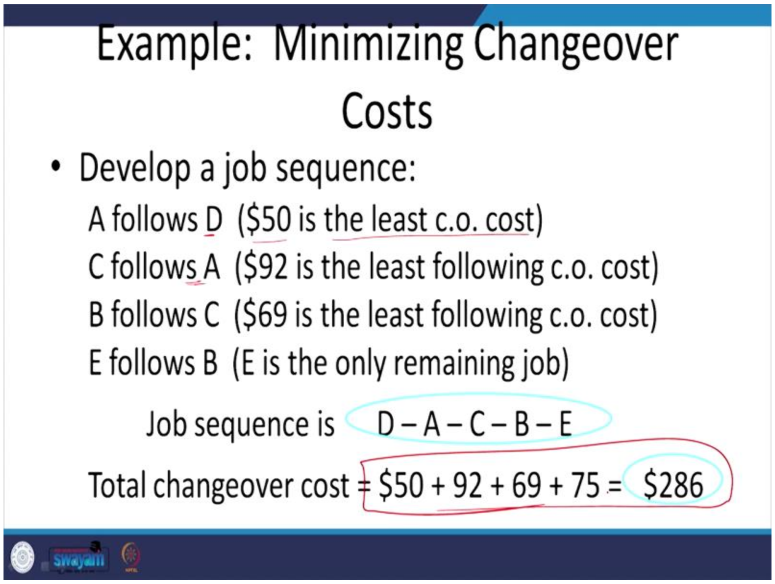


Jobs That Follow \ Jobs That Precede	A	B	C	D	E
A	--	65	80	50	62
B	95	--	69	67	65
C	92	71	--	67	75
D	85	105	65	--	95
E	125	75	95	105	--



For an example, this is a particular type of diagram and this changeover cost issue is to some extent, those who are familiar with operation research they will find that it is similar to assignment problems. So, that how a travelling salesman problem is designed similar to that this kind of problems are being handled. So here, you have A, B, C, D, E five jobs and these are mentioned on both the sides.

So, if job A is there, so what will be the cost if job B will be done after A, what will be the cost if job C is done after A, what will be the cost if job D is done after A. And that is how this entire matrix is being presented, that what will be cost of changeover if after a particular job another job is done. After E, E is done and after E, if I want to do A the cost will be 62. After D, if I want to do C the cost will be 67. So, that is how you will read this particular table.

Now, you will develop based on our heuristic, you will develop this kind of job sequence that after A if you follow D, so it is 50 dollars is the least changeover cost, A follows D. So, if you see the A follows D, then it is the 50 dollars. A follows the D, D is this, and after D you are doing A. So, the this is the lowest cost. So, first you identify out of this which is the lowest changeover cost.

So, in this entire matrix 50 is the lowest possible cost. So, you have freezed one sequence that after D you are going to have A. Now, since you have fixed after D, A, so you will see that C follows A, that is another important thing because now you will see that the next job should be after this. So, after A you cannot have this D, so this is out. And out of the remaining 95, 92, 125 this is the lowest. So, after A you will have C and now you want next job to be done after C.

So, after C you will not do D, because D is already done and A is already done. So, out of this two B and E, B is the minimum. So, this you will select as your next cost, next job that is B. Now, you have after B, already D, A, C, B four jobs are being selected, so the next will be E. This becomes your sequence, D, A, C, B, E and the cost of this particular plan is 286 dollars. So, that is the minimum changeover cost system, also that is going to help you in minimising the cost of your total system.

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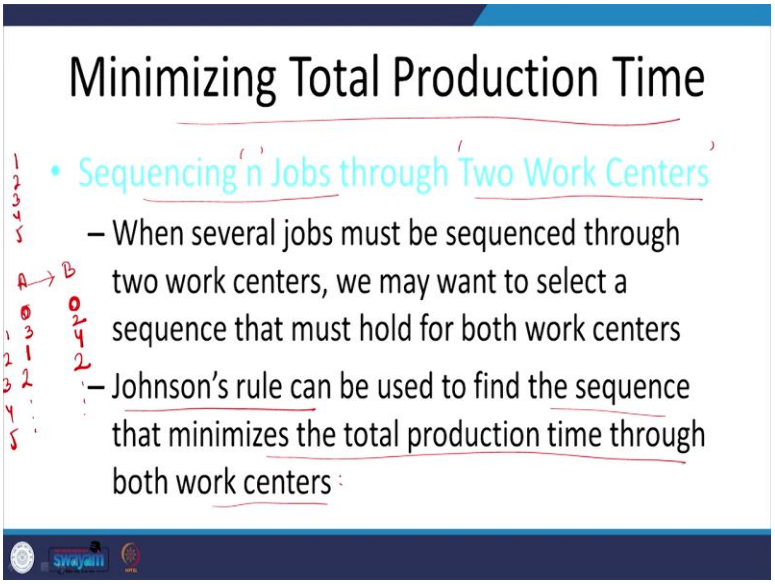

Then, another important issue in this particular case is to minimise your total production time, how to minimise your total production time. Now in this particular case, where you have jobs which are n in number, n jobs and two work centre, there can be multiple cases but we are going to discuss only one particular case that jobs are infinite, jobs are n, and work centres are two. You can have three or more work centres also, but we are not going to complicate just going to introduce you that how to sequence various activities on two work centres.

So, means you have these two work centres A and B and there are jobs like 1, 2, 3, 4, 5 and all these five jobs require some operation to be done on A and some operation to be done on B. And the sequence is also fixed, that first it will be done on A, and then it will go to B and, but they will take some different time of processing on A and B. Like for A, 1, 2, 3, 4, 5 it takes 3 minutes here, it takes 2 minutes here.

It takes one minute here; it takes four minutes here. It takes 2 minute here, it takes 2 minutes here, so on you have different time taken by different jobs on these two machines. So, how we can sequence these things, so Johnson's rule is known, which is used to find the sequence that minimise this total production time through both work centres.

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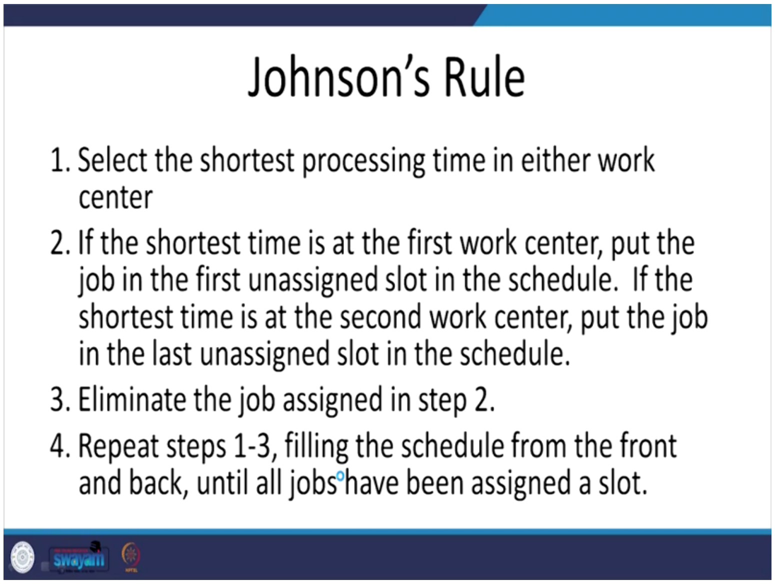

So now let us see how do we have this Johnson's rule applicable. Now for this purpose, we have this theory also available with us that what are the various steps to take this minimum scheduling time.

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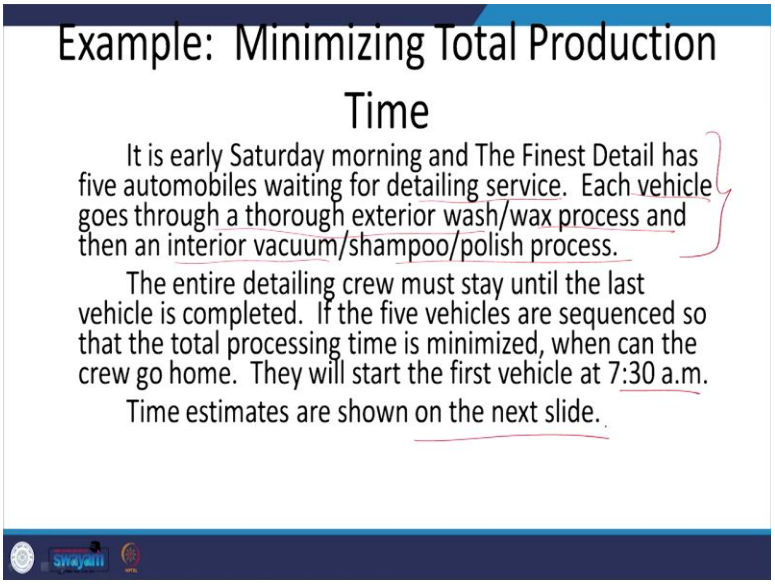

And with the help of one example, we will like to do this particular Johnson's rule application. Here, it is the theory of that example. It is early Saturday morning and the finest detail has five automobile waiting for the detailing service.

Each vehicle goes through a thorough exterior wash, wax processing and then an interior vacuum shampoo and polish process. So, you have different types of cars available and the cars are cleaned interior and with exterior also. The entire detailing clue must stay until the last vehicle is completed. If the five vehicles are sequenced, so that the total processing time is minimised, when can the crew go home. They will start the first vehicle at 7:30 a.m. And now, we see the time estimates for different types of jobs.

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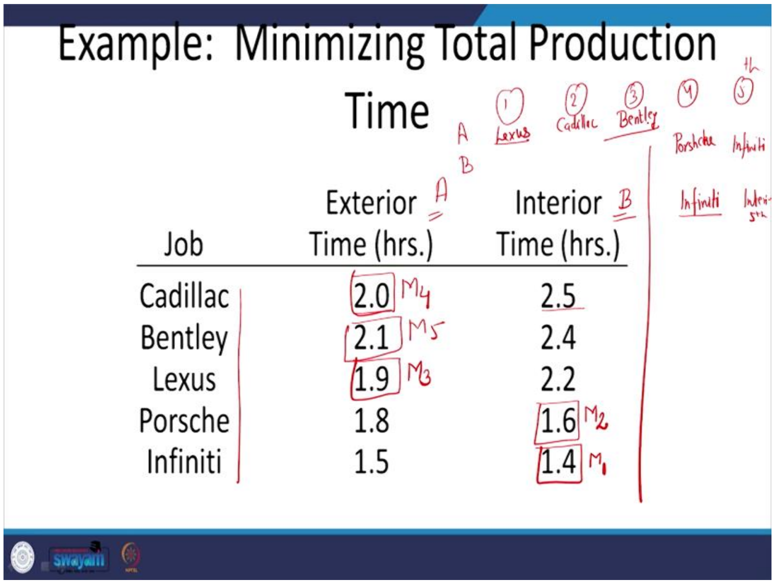

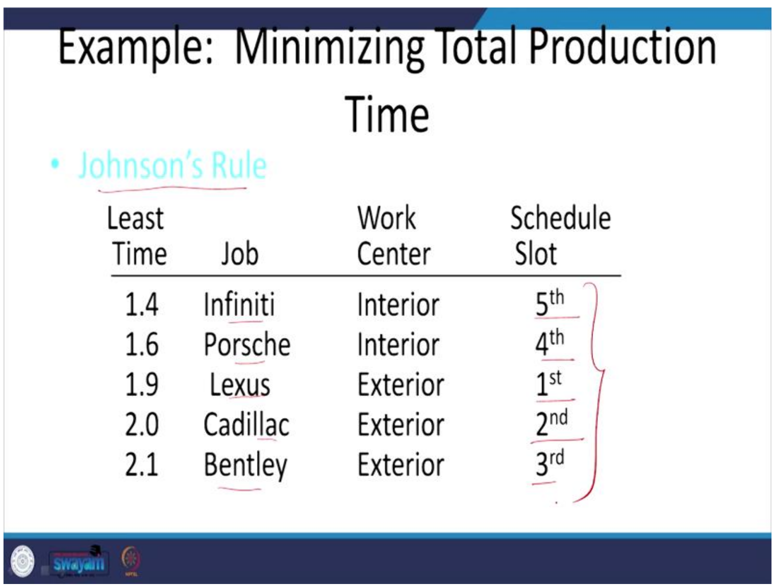

So, there are these five different types of luxury cars and you have time taken for the exterior work and for the interior work for these different types of, so the exterior work and the interior, these are the jobs. And these are the two you can understand, machines or the work centres.

The exterior time is one type of work centre and interior time is another type of work centre and we need to just develop a sequence that which machine or which particular job to be processed first, and accordingly we will go further.

Now, by applying the Johnson's rule, by applying the Johnson's rule we see that out of two, out of two because it is a fixed schedule, that first exterior and then interior. Now out of all the time estimations available we will see that which time is the minimum and the minimum time is the first, M1, this is minimum 1. And therefore, the first job to be scheduled is Infiniti but it will be scheduled for the last position for the B for interior, interior fifth position.

Because you have five machines, five jobs, so there will be five positions; first position, second position, third position, fourth position, fifth position. So, at the fifth position, so for A and for B like this. Now, you have scheduled Infiniti at the fifth position. Now, the second lowest value is after this is this, 1.6, that is the M2. So, this will go for the fourth position again on the second because the lowest times are coming from the second table that is Porsche. So, this is the fourth position.

Then out of the remaining three the lowest is 1.9, that is M3. Now this M3 is coming from the first column, so this will go to the first position in your A category. So, Lexus will take the first position. Then out of these two, Cadillac and Bentley the minimum time is coming 2, that is M4, so this will take the second position at the work centre 1. And then obviously, the only time available is 2.1 that is the M3, M5 and this will go to the third position here. So, this is the sequence that, Lexus, Cadillac, Bentley, Porsche, and Infiniti, in this way you will have your jobs.

So, Infiniti is for the fifth slot, Porsche for the fourth slot, Lexus for the first slot, Cadillac for the second slot and Bentley for the third slot. So, in this way we have fixed these slots using the Johnson's rule.

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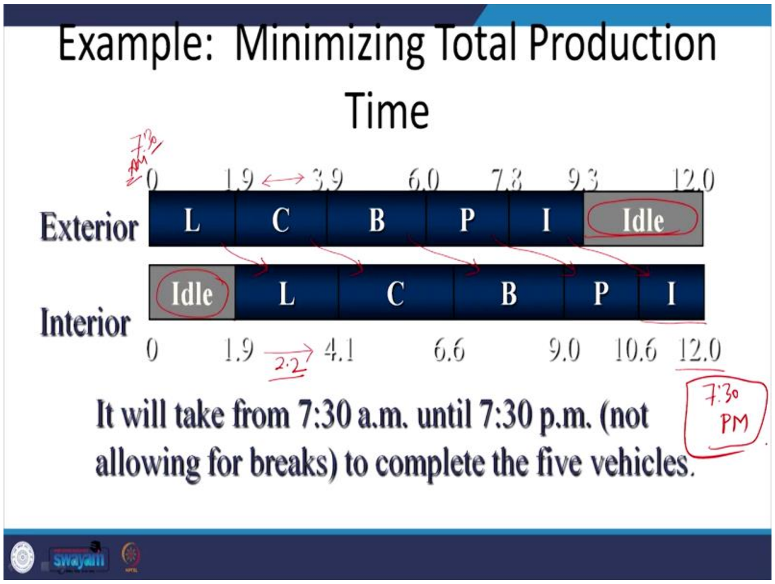
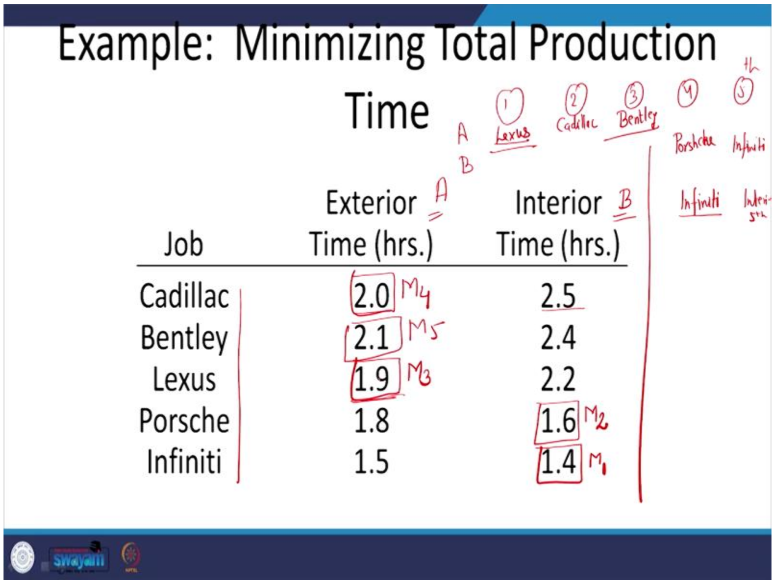
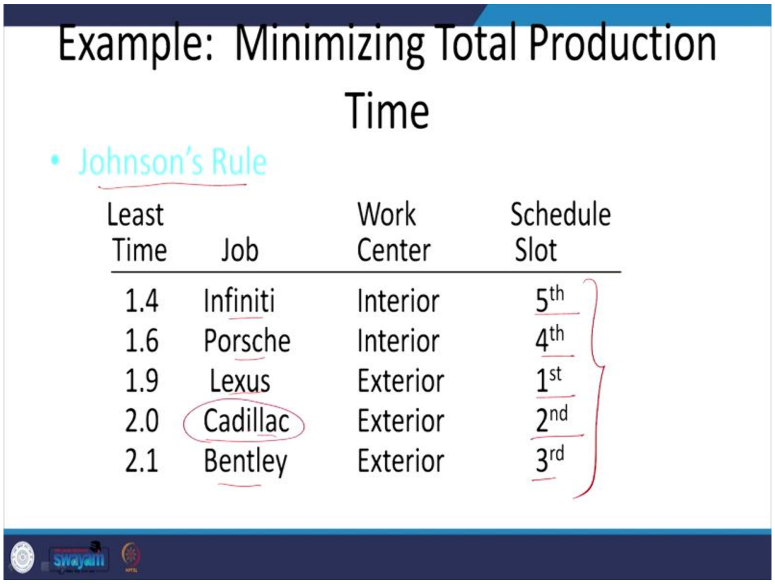




Job	Exterior Time (hrs.)	Interior Time (hrs.)
Cadillac	2.0	2.5
Bentley	2.1	2.4
Lexus	1.9	2.2
Porsche	1.8	1.6
Infiniti	1.5	1.4



And when we have the presentation of this Johnson's rule, on this type of a Gannt chart you can say, this will give you that how long the service is going to remain there, how long the crew has to stay at the workshop. So, we are starting at the morning 7:30 a.m. and we will start with Lexus, the first work we are going to start with the Lexus. And at that time, you see your, the second work station in remaining idle.

Now, the Lexus is taking 1.9 hours, it is taking 1.9 hours Lexus is taking for exterior work, 1.9. So, only after 1.9 hours the work station two will come into picture. After 1.9 hours, Lexus will go to work station 2 and it will take 2.1, 2.2 hours for completing the interior activities. Then the second was Cadillac. So, Cadillac will start after 1.9 and it is taking 2 hours, so it will be with work station 1, and after that Cadillac will go to here. Then Bentley, then Porsche, and last is Infiniti. And here this Infiniti is going to finish at the twelfth hour, but for this much duration the first work station will remain idle.

So, the first work station is remaining idle at the end period and the second work station is remaining idle in the beginning of the workshop. But total duration which you are taking in the workshop is 12 hours. So, the workers, the garage opens at 7:30 a.m., your crew comes at 7:30 a.m. but crew will be able to depart only at 7:30 p.m. So, that is the total production time in a particular case when you have two systems and multiple jobs to be scheduled on these two systems. But this is the minimum time, though this is heuristics, it is not based on any kind of algorithm. It is a heuristic, but it gives you the minimum time for completing the total activities.

So, with this we come to end of this session, where we discussed various types of sequencing rules, we discussed how to minimise our total changeover cost, and how to minimise our total production time. All these things are very important criteria in developing a good, robust scheduling plan. So with this, we finish this session. Thank you very much.