Logistics & Supply Chain Management

Professor Vikas Thakur
Department of Humanities & Social Sciences
Indian Institute of Technology, Kharagpur

Lecture 47 : Sequencing & Scheduling

Hello, dear friends. Welcome back to NPTEL online course on logistics and supply chain management. Today, we'll start discussion on sequencing and scheduling. So in the last session, we discussed about capacity planning, and we discussed how we are supposed to plan our resources. We need to plan the capacity so that we can meet the requirements coming from the customer end. in terms of demand quantity quality whatever right.

So, now the very next thing is once you are planning your capacity obviously, it is very important to you know define in what order in what sequence you need to process all the jobs right. You have different jobs in one project whenever you are producing product as well right. So, in this session we will discuss about in what order sequence you should plan your jobs right. and then we will see how we can schedule those jobs for different machines if we have one machine we have multiple jobs how we can schedule that machine if we have two machines multiple jobs how we can and sequence is same how we can schedule those multiple jobs on two machines and then three machines and then n number of machines Obviously, jobs will always be higher number of jobs will be right so we have a limited number of machines 2 3, or more than that then we will see how optimally we can make this assignment allocation of different jobs on different machines so that the total cost can be So, first we will discuss about the sequencing rules and we will see what are different advantages and challenges when we are implementing the sequencing algorithm and then we will talk about the scheduling, how we can schedule multiple jobs on two machines by using Johnson rule and then three that Johnson rule can be extended for three machines as well and after that if more number of machines are there then we have special case of assignment problem which we will be discussing in the further session.

So, sequencing as I told you is order of processing a set of task, how we should plan all the task in particular sequence and scheduling is sequencing as well as we will find out the time. how much time is required on one machine how will move from one machine to other machine the same job because that job requires processing on machine 1 as well machine 2 as well and then will go on machine 3 or may be more than that right so then we will find out how we can sequence those jobs and then the time required for all those machines for those particular jobs. In the first part, we will talk about only sequencing these tasks over one workstation. These guidelines are used to determine the order in which the jobs or tasks should be processed to optimize the performance and efficiency obviously, this is the main objective that the efficiency should be higher and optimally, we should use the resources so here the point is minimizing the total processing time that is we will calculate in terms of flow time right and how we can reduce the delays. We should assign the order decide the order in such a way there should be minimum waiting time throughout that channel and then how in that way we will ensure the resource utilization.

So, we will talk about the sequencing rules. This is first in first out. Usually we are following this. If you are going to bank, if you are going to post office, if you are coming for exam first in first out. right evaluation right so those things are there when we are using the this kind of situation we are using first in first out algorithm right so very obvious as the jobs are arriving a is the first b c d e so this is the sequence so i am believing a came first then b then c then d and e So, this processing time is known for each job this is the requirement pre requirement of defining the sequence and then the due date is also given due date means when I need to deliver job A may be after 5 days job B after 6 days likewise.

Now, I am interested to find out the flow time and whatever is the delay using first in first out algorithm. obviously our first job is A job will be assigned on the very first day and will take 3 days so obviously after 3 days this job will be over on fourth day job B will come and the processing time required is 4 days so total will be 7 days On 8th day, C job is available, time required is 2 days. So, total flow time will be 9 days, it will be completed. And then D job will come, it requires 6 days and or whatever unit is, yes, it is 6 days. So, then it will require 9 plus 6, 15 days.

And last E job requires 1 day. So, total flow time, this will be the sum of all these flow time, 3 plus 7 plus 9 plus 15 plus 16. And then you can find out the average flow time that is required for each job is coming 10 days for when you are using first in first out algorithm. now i want to find out the delay by using this particular algorithm so job a we are delivering after three days it was supposed to be after five days so we are well on time job b we are delivering on seventh day but it is supposed to be on sixth day so one day delay is there C we are delivering on 9th day and we are supposed to deliver on 7th day 2 days delay is there job D we are delivering on 15 days after 15 days and we are supposed to deliver on 9th day so that is 6 days delay is there similarly for E 14 days delay is there so you can sum up the total delay and average delay per job is 4.6 days if you are using first in first out sequencing algorithm.

Right now, we will go for the second algorithm that is last in, first out, and these are situations when we are processing the last one first. Let's say if you entered first on the left, you will come out last from the left-right if you are going you are submitting all the books right 10 students are submitting the books to the library so there is a stack pile there so they will process the latest one first then we will pick the second third fourth and the book which came the first will be processed in the last right so there this is also algorithm we are using for last in first out again so then the job sequence will be reversed e d c b a and accordingly processing time is given now let's find out the flow time zeroth day i'll process e job requires one day so total will be one so then after that one plus six because d requires six days it will be seven then seven plus c requires two days it will be nine so nine plus four So, it will be 13, B will be delivered on 13th day after 13 days and then 13 plus 3, A will be delivered after 16 days. Again you can sum up all these flow time and you can see 9.2 days per job is the average flow time. Let us talk about the delay.

Job E, we are supposed to finish by 2 days, we finished in 1 day no delay. Job D, we are supposed to finish 9 days, we finished in 7 days no delay. Job C, 7 days should be, but we finished on 9th day, 2 days delay is there. Job B, 6 days should be there, but we finished on 13th day. That means, 7 days delay is there, job A due date is 5, but we delivered on 16th day, 11 days delay is there.

So, you can again find out the average delay is 4 days per job. the another sequencing rule is shortest processing time whosoever is the shortest processing time will be processed first but the problem with this type of algorithm is if anything is taking the longest time that will be delayed for infinite time right you cannot decide so that is the only job left out and then you will do that job Right so you are not taking care of the due date and all those things so that also some time is important if let's say you have one job pending which requires five days processing time and you need to deliver after maybe six days and there is another job which requires the processing of only one day but you need to deliver after 15 days, but you are producing that process you are processing one day job first because the shortest processing time Even though you need to deliver that by the fifteenth day, this is the limitation of the shortest processing time. As you can see, I have sequenced all these jobs according to their due dates. The flow time can be calculated as follows: on the zeroth day, one day is required. Then, one plus two equals three, and three plus three equals six days required for job A.

Finally, six plus four equals ten days required for job B, and ten plus six equals sixteen days required for... So, in the end, you can sum up the flow times and see that the average flow time is 7.

2 days. Now let us determine the delay for job E. We finished it on the first day with no delay because the due date was in 2 days. For job C, we finished in 3 days, and the due date was in 7 days, which means there was no delay. For job A, we finished on the 6th day, and the due date was in 5 days, resulting in a 1-day delay. Finally, job B has a flow time of 10 days.

It is supposed to be finished in 6 days, but there is a 4-day delay. Job D has a due date of the 9th, and we finished on the 16th, resulting in a 7-day delay. However, you can see that the shortest processing time is shorter when we follow this method compared to last in, first out, and first in, first out, where the average delay is only 2.4 days, right? The other sequencing algorithm has the longest processing time, which is the opposite of what was stated. So, that means the longest processing time will be handled first.

(The sentence is already grammatically correct.) This is how you arranged it in descending order. (The sentence is already grammatically correct.) So, again, for flow time, you can simply calculate: 6 plus 0 plus 6, 6 plus 4 days required for B, 10 plus 3 days required for A, 13 plus 2 days required for C, and 15 plus 1 day required for E. Then, you can compare the due date with the flow time.

There is no delay here; we are delivering after 4 days, while in another case, we are delivering after 5 days. There is an 8-day delay, a 14-day delay, and again, you can see an average delay of 6.8 days. The longest processing time is likely taking the most time, and the average delay is very high for processing all these five jobs. The other rule you can opt for is the sequencing rule of the earliest due date; whichever item you need to deliver first, you can process that one first.

Therefore, you will schedule the due date, and you need to finish this within two days. So, let us process this for 5, 6, 7, and 9 days. (The original sentence is already grammatically correct.) So, this is how you have sequenced all these processing times: the flow time can be calculated as follows: 0 plus 1, which equals 1; then 1 plus 3 days required for A; 4 plus 4 days required for B; 8 plus 2 days required for C; and finally, 10 plus 6 days required for D.

The sentence "Right." is grammatically correct, but it lacks context. If you meant to express agreement, you might say, "That's right." If you need help with a different context, please provide more details! So, you can find the average total flow time. (The original sentence is grammatically correct.) So, let us find out the delay in job E, which you were supposed to deliver after 2 days but delivered perfectly within 1 day.

Job A was also completed within the time limit, while job B was delayed by 2 days; you finished it on the 8th day when it was supposed to be completed on the 6th day. There is a 3-day delay for Job C and a 7-day delay for Job D when you compare them in a ratio of 16 to 9. The total average delay for all the jobs is 2.4 days when the earliest due date algorithm is used.

The next algorithm has the least amount of slack. So, is Slack how you find out about the updates? Slack is the difference between the due date and the processing time. So, the job with the minimum slack time will be processed first, right? This way, there will be very little time left before the deadline. Your correction is almost correct, but it can be improved for clarity.

So, this least slack is intended to complete those tasks first. So, we will first process those that need to be processed. So, obviously, you can determine the slack time for all of these activities. Here, I have calculated that the minimum slack time remaining for the job is for Job 5, so it will be done first in the sequence.

Then the next minimum is 5 and 5. You can choose either Job 2 or Job 4 arbitrarily, as both take the same amount of time. So, there is no point in this. The sentence is already grammatically correct. However, if you would like to enhance clarity, you could rephrase it slightly: "So, 2, then 4, and finally 1 and 3." This is the sequence, and again, you can determine the flow time and the average time.

This is a simple least slack method. The next one is the critical ratio. Now, you are calculating the critical ratio by dividing the total remaining time until the deadline by the total remaining production time. The critical ratio is calculated using the time remaining until the due date and the required processing times.

Again, the job with the minimum critical ratio will be processed first, correct? So, the due date is provided, the processing time is given, and you can calculate the CR and critical ratio for Job A (2), Job B (5), and the ratio (2.5:1). So, you can see that you should process job D, then job A, followed by job C, and finally job B, according to the critical ratio of D, A, C, and B. This is where you can observe the final sequence, and then you can easily determine the flow time as we did in all those previous examples.

Subsequently, you can find the delay. So, actually, you can compare all these algorithms to see which one takes the maximum time, the flow time, and the delay, as well as the maximum delay per job, right? This is something you can easily discover. So, what are the advantages of sequencing. Clearly, we can avoid the bottlenecks

Adaptable planning is important because when you use the critical ratio method or the earliest due date in your algorithm, you are implementing dynamic programming. Every day, the ratios change, allowing you to plan your resources accordingly and sequence the jobs effectively. So, there is a possibility of choosing a set of standard rules.

So, there will be no conflicts. So, we are using one of these algorithms. So, if I know I am first in the sequence, I will be processed first. The original sentence is indeed grammatically correct; no corrections are needed. That doesn't matter whether I am in an emergency or urgent situation; regardless of the circumstances, it is because they are following a first-come, first-served algorithm. Lean production will be implemented because we have standardized these algorithms.

Thus, we can avoid the waste associated with decision-making and adjustments. The customer can adapt the process sequence to their unique requirements. "Right, and this will enable us to plan, process, and understand everything. Then we can handle it in that way, and we are also prepared with the programming in case something goes wrong. So, what will be the next step in the sequence? We can also plan for that.

Obviously, there are some challenges, as we are stating that it is dynamic and that we are making changes." Very frequently, when you plan something yesterday, it changes today due to the critical ratio. Now, you are planning a different sequence, which makes it very difficult to standardize the process. This can happen if you have an adaptable algorithm and limited availability of resources such as machines, labor, and materials. Additionally, you mentioned that the initial sequence is A, B, C.

These jobs will be done correctly, but we are currently struggling to obtain the raw materials for processing. According to our algorithm, we should process in the correct order, which means there is a problem with the sequence. We are not considering the resources, so sometimes we need to change that as well, which is causing delays. Therefore, the issue of optimality is also in question. What if we have large-scale operations? Then, every day, thousands of jobs require you to shuffle back and forth, which can be very confusing, especially when balancing different prioritization criteria, such as due dates, job importance, and customer requirements, as these can lead to conflicts.

Therefore, if you are considering this, it’s clear that importance is not the only factor to take into account when delivering the product. For instance, sometimes importance may mean that if I am working on Job A and Job B, I might focus on Job A because I need to deliver it early. But the due date for Job B is later, and the customer, who is a frequent, loyal, and regular client benefiting from Job B, generates significant revenue for me. Therefore, I am not considering those factors, and they are not included in this sequence.

Right, so the second part of this session is scheduling, where we will define the sequence for multiple jobs. This time, we will be working with more than one machine. Earlier, we considered only one workstation and how we would process A, B, C, and D on that workstation. Now, we will have at least two machines, and again, there will be multiple jobs.

We have some computer software where you can input any algorithm and then implement it. Initially, we will do this using your Johnson rule. The point here is that we are allocating the start time and finish time based on the processing time required to perform each job. So, by using the Johnson algorithm, we will find the sequence. So, we will solve one or two numerical problems, and we will see how we can work on a single machine.

See, these jobs are available. There can be an infinite number of jobs, and we have two machines. The processing time for each job on machine 1 is provided, and the processing time for each job on machine 2 will also be given. Here, we are assuming that all jobs will follow the same sequence: job A will go first on either machine A or machine B, but it will be processed on both machines. Right, so this is the structure of the problem, and this is the algorithm you can follow.

There are some conditions: the time for each job should be consistent and known for machine 1, machine 2, and machine 3. The sentence is already grammatically correct: "How many machines are there?" So, that time should be acknowledged. Job time must be mutually exclusive from the job sequence. All jobs must be processed in the first work center before proceeding to the second work center: first the first machine, then the second, and finally the third.

All jobs are prioritized equally This is the assumption that all jobs are equally prioritized, and then we will apply the Johnson rule to sequence them. You can simply follow these steps; I will use them to solve this problem, and you will come to understand how we can solve the problem using the Johnson rule. Now, Johnson's rule states that the first step is to list the time required to perform the job on Machine 1 and then on Machine 2.

Here, we have listed the times for jobs A, B, C, D, and E on machines 1 and 2. Therefore, we have five jobs. Now, the algorithm states that we need to find the minimum time required to complete any job on any machine. I believe the minimum value here is 1.

5." There are no errors to correct. You mark that job; this is Job B. If this minimum time is on Machine 1, place that job first in the sequence. If it is on machine 2, place that job last in the sequence.

The sentence is already grammatically correct. So, because the minimum time is on machine 2, we will place job B last in the sequence. The sentence is already grammatically correct. Once it is placed, you will strike it out. Now, this machine is unavailable.

Now, I will repeat: just imagine that we have only four jobs. The original sentence is indeed correct. No grammatical changes are needed. I think 2.2 is now the minimum value. If this minimum value is on machine 1, place that job first in the sequence.

If it is on machine 2, then the job is last in the sequence. The sentence is indeed grammatically correct, but if you want a slightly more concise version, you could say: "Being last in the sequence means that this block is now the last one only because the previous block is already occupied." However, your original sentence is perfectly fine as well. If the first position is occupied, then this one will be first, right? So, here, C will be placed first in the sequence because it is on machine 1. Then we have three jobs; the minimum time, I believe, is 2.

8, which is for E. Machine 2 will be placed last in the sequence. Now that E is also gone, the minimum time is 3.

2, which is for job A on machine 1. Obviously, the only one left is... The sentence "This." is already grammatically correct, but it is incomplete as it lacks context. If you intended to express something specific, please provide more details.

So, C A D E B. As you can see, all these steps are represented as C A D E B. This is how we can sequence them using Johnson's rule. So, this rule can be replicated for more than two machines. However, I will find out how we can determine the time required for each machine, as this information is not provided here, and then we can allocate resources accordingly. The original sentence is indeed grammatically correct. However, if you want a slightly different phrasing, you could say: "I need one of these tables; I will only do it here.

" Let's say that this is for Machine 1. So, machine 1's first job will be your C. C is coming on the 0th day. How many days are required? Let us say that I am stating that this time is measured in days.

How many days are required for Job C? 2.2 days is required. So, it will be available in 2.2 days. The next job in the sequence is A. How many days are required for Job A on Machine 1? So, that means if I add 3.

2, it will equal 5.5. The next job in the sequence is D. How many days does D take? 5.

8 So, that means the total will be 11.8 if I add 5.8 to 5.4. Then, the next job in the sequence will be E.

So, how many days does E require? 3.1 So, if I add 3.1, it will obviously be 14.4. The next job is B, and the last job is also B. How many days does it take on Machine 1? It seems that your request is incomplete or lacks context. Could you please provide the full sentence you would like me to correct? 22 days So, all five jobs will take 22 days on machine 1. Let us now plan for machine 2. The sequence indicates that job C will be processed first on machine 1, which means that, up to this point, machine 2 will be idle because there is no job to process.

Currently, we are processing job C on machine 1 for an initial 2.2 days. The machine 2 will be idle, and after that, C will come. C will take 5 days, which means 2.

2 plus 5. So, how many days will it take? It will take 7.2 days. (Note: The original sentence is already grammatically correct.

No changes are needed.) So, 7.2 days will be approximately here. After 5.4, I am just referring to this randomly, but yes, since this is the 5.

4 timeline, I am writing 7.2 here. So, C took 5 days and 7.2 hours. (The original sentence is already correct.) Now, A is available. (The sentence is already correct.) A is available on April 5th.

So, can we process it immediately? Yes, we can process it because we are on day 7.2, and a job is available on day 5.4. So, a job will take 4.

2 days on Machine 2. The sentence is grammatically correct as it stands: "So, that will give you 11.

4." So, 11.4 will be a little lower here because 11.2 is present. So, 11.4. Now, the next job is D. Is the D job available at 11:40? Yes, it is available because we will finish D on machine 1 at 11:20. So, we can start Job D on Machine 2 immediately. Now, Job D requires four days to be completed.

So, that means four days. When will we finish it? We will finish it in approximately 15.4 days from now. (The original sentence is already grammatically correct.) So, it takes 15.4 days to determine whether the next job is available.

The next job is E, and yes, E is available in 14.3 days. We can start job E right away. How many days does it require on machine 2? If I add those 2.

8 days, the total will be 18.2, which means, let us say, that 22 should be here. The sentence "So, 18.2." is grammatically correct as it is. If you would like to provide more context or a complete sentence, I would be happy to assist you further! Now, the next job is obviously the remaining one, which is Job B.

Is Job B available at 18.2? No, the B job is available in 22 days. That means I need to wait this long. So, how many days will Machine 2 be idle this time? 3.

8 days plus 18.2 days equals 22.0 days. So, we will come here at 10 p.m. So, this delay means there is no idle time for machine 2 because the processing of that particular job, which is B, has not been completed on machine 1. So, on the 22nd day, we can start your Job B, which requires 1.

5 days. So, finally, we will finish this job on May 23rd. So, if I state the total time required, it will be 23.5 days because we are starting on the 0th day here on machine 1 and ending on machine 2 at 23.5 days. Let us consider the idle time of machine 1 and the idle time of machine 2. Machine 1 is starting immediately at 0 today, but it will start after 22 days because the last operation we are performing will take 22 days.

So, after that, it will be idle if we are not processing anything else. The sentence is indeed grammatically correct as it stands: "So, 23.

5 minus 22 equals 1.5." So, that means there are 1.5 days of idle time for Machine 1. Machine 2's idle time was initially between 0 and 2.2. Machine 2 did not operate because we were waiting for the first job to be finished on Machine 1, and in the meantime, we waited for this 3.

8 time period. The total is that machine 2 was idle for six days. This is how we can sequence the jobs and determine how much we are utilizing each machine. The sentence is already grammatically correct. Now, we will expand this algorithm to include three machines.

You can simply follow this algorithm. The original sentence is indeed grammatically correct. However, if you're looking for a slight variation, you could say: "I will simply take this example." Now, to initially determine the sequence, we will convert this three-column matrix into two columns: one for \(a + b\) and another for \(b + c\). I will add these, and I will again consider those two columns as two machines. Once I add them, this will give us the new processing time.

The algorithm remains the same: we need to find the minimum time. I believe the minimum time is eight, and it is for two. So, for Job 1 and Job 4, So, when it is for machine 1, place it first in the sequence. So, 1 is gone, and 4 is gone. I think the next minimum is 9, and it is on machine 1.

So, put that next in the sequence; this is also gone. The next minimum is, I think, 11, which is the total for machine 1. That means 3, so right away we have this sequence: 1, 4, 5, 3, 2. Now that we have the total, we need to find out the time. Therefore, we need to calculate for all three machines. This sequence is 1, 4, 5, 3, 2.

Sure! Here's the corrected version of your sentence: "Alright, let us draw this now for Machine 1. Machine 1 is arriving at Jaw 1 on the very first day, and it requires 4 days. Therefore, for Machine 1, it takes 4 days. Next, the fourth machine requires 6 days, so the total will be 10 days.

This is for Machine 1." The sentence "Job 4" is too brief to correct for grammar, as it lacks context and structure. If you meant to say something like "This is Job 4" or "Job 4 is complete," please provide more context so I can assist you better. Then the 5th requires three days. So, somewhere here is 13, and this is job number 5. And then, 3 requires 8 days.

So, obviously, 8 days are required for job 3, and then we have job 2, which requires 9 days on machine 1. You can simply add those 9 days, and it will be scheduled here for job 2. So, all the jobs for machine 1 are done. Now, let us move on to machine 2. Similarly, we will proceed to machine 3.

For the first four days, machine 2 will be idle because the first job is being processed on machine 1. (The original sentence is already grammatically correct.) Now, job 1 will come after the fourth day, and it requires four days for processing on the machine. So, 4 days means 8 somewhere around here. Now, the next job will be available in 10 days, which is the 4th.

This 4 is available after 10 days, right? So that means we cannot start a statewide operation; this again represents idle time. We will start on the fourth day, which is the tenth day. Please note that there is a 2-day delay here, so initially for machine 2, there is a 4-day delay followed by a 2-day delay. You need to keep adding, right? Here, the space is a little smaller, which is why I am writing less. Otherwise, you can also draw machines like this, which is better. So, wherever you are assigning a value, you can write "two days," and if you are not assigning a value, you can note that this is a one-day delay.

Right? Next is the fourth job, which requires two days, so we will finish on the twelfth day. Now, you see, we need to wait for one day because your job 5 is not available. So we are here, and we are waiting. Job 5 will require 6 days on machine 2, which I think makes it 13 plus 6, totaling 19, right? Also, job 3 will not be available for the next 2 days.

So, we will start on the 22nd and begin the third job, which will take 3 days. So, it will take up to 24 hours. (The sentence is already grammatically correct.) Here is the corrected version of the sentence: Then, we need to determine whether the last job is available after 30 days. This means there will be a delay or idle time for machine 2 for 6 days. On the 30th day, it will arrive at machine 2, and job 2 will require 5 days to complete.

Therefore, it will take a total of 35 days for machine 2 to finish. So, you see, this is the idle time for Machine 2. Similarly, you can extend this to machine 3, and I will just complete the first one. For the first eight days, your machine 3 will be idle because only your job 1 will be scheduled for machine 3 after that period. So, there was an initial delay of 8 days; how many additional days were required after that? 14 will be somewhere around here.

(This sentence is already grammatically correct.) So, you will be processing your first job at 2 PM. So, after 14 hours, your job will be available for 12 days. So, you can start right away because today is the 14th day. So, there is no delay in finding out how many days are required for Job 4. Eight days are needed, and you can keep adding 22 here. You can also find the waiting time, and this is how you can determine the idle time for each machine, as well as the waiting time for each machine.

So, this is how the Johnson Rule can be extended. You can see that I have calculated this for all of these machines. There are different methods available: you can use this table format, draw lines, draw boxes, or find other ways to utilize it. Now, what if we have more than three of your machines? So, in the next session, we will discuss the assignment problem, where we will examine a matrix listing jobs (Job 1, Job 2, Job 3, Job 4, Job 5, and so on) and machines (Machine 1, Machine 2, up to Machine m). The costs of assigning each job to each machine will be provided, and we will solve the assignment problem to determine the optimal assignment that minimizes the total cost.

We will have a separate session for this. For this, it is all about sequencing and scheduling. So, these are the references, and you can practice some additional numerical problems with them. So, that is all for this session. Thank you very much