Project Management
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Module No # 06
Lecture No # 30
Resource Leveling and Resource Constraint

Welcome back my dear students this is the continuation of the project management course this is the thirtieth lecture which I am going to start now. And if you remember I did mention very briefly that why the crashing of the jobs would be required? Crashing means you want to reduce the time and obviously then you need to basically consider what are the resource, constraints of the resource implication which you have for your problem.

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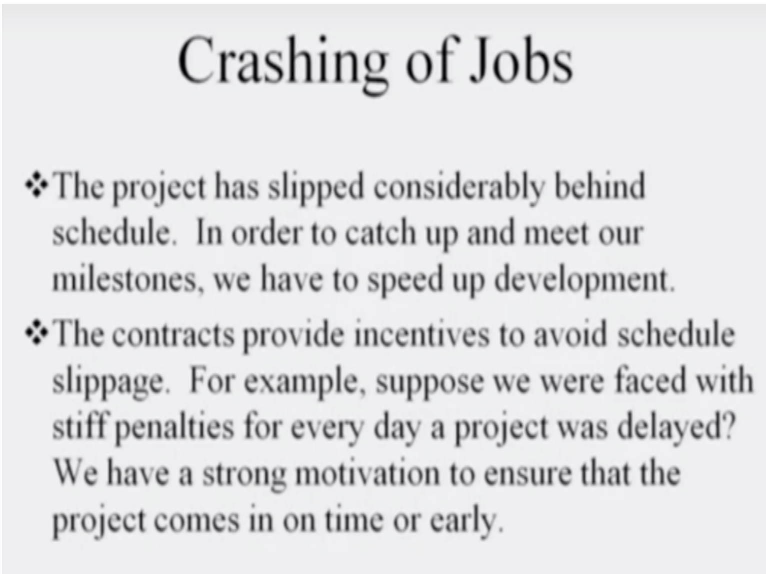

So continuing with the same discussion, the project has now, with some of the reasons which we are discussing, the project has slipped considerably behind schedule. And you need to basically crash the set of jobs or the activities to finish the work on time. So in order to catch up we meet our milestone and the deadlines, we have to speed up the work of the project. The contracts provide there may be such cases, so I am just reading out some the actual reasons why you may be interested to crash the project or the set of activities.

The fourth point is the contracts provide incentives to avoid scheduling slippage for example, suppose we were faced with stiff penalties for every day the project was delayed. So, I did mention this point that if you are able to deliver for the last example, which we considered in the twenty-ninth lecture discussion, the average time was thirty weeks. And somehow the contract was such, that it was say that if you are able to deliver within the thirty-two weeks, you get some benefit like some extra um income, or some bonuses you can get.

I am just, or say for example you are assured that you will can be able you are competent enough to get the next project on hand. But on the flip side also, if you exceed the thirty-two weeks deadline there is a penalty. Penalty can be you have to pay huge amount of cost or the overall price deduction would be there. The depreciation concept would be come into the picture, where you make a loss.

So these may be some of the stiff penalties which you as a project manager or a team leader can face. For which you have to take a decision whether it is actually feasible to crash the set of jobs for the project.

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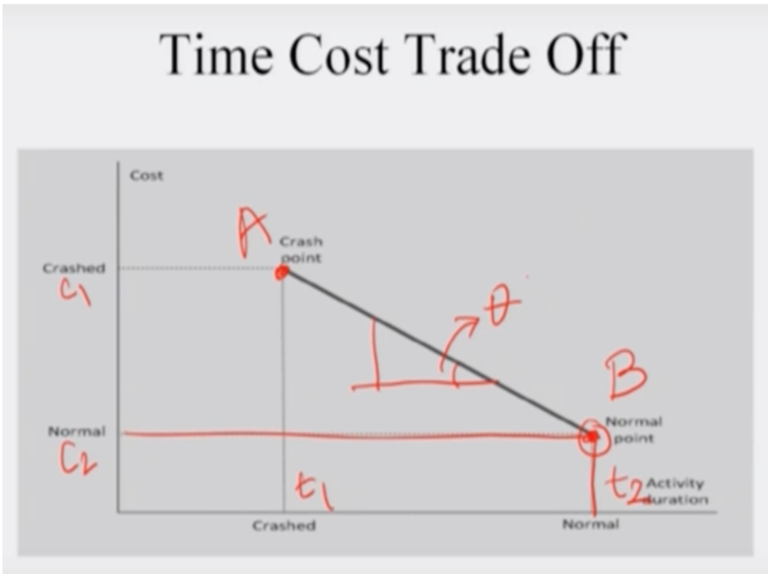

So let us consider the graph which is there in front of us which is the three sixty-third slide. So on the y-axis you have the cost, so I am considering the cost overall. It is nothing to do with input cost or output cost, I am just considering cost as a factor, point 1. And along the x-axis I am basically considering the duration in days, in weeks, whatever it is. Now there is only one important point to be mentioned.

I am considering the concept of the relationship between the cost and the factor of time is linear in nature. So if you consider point number a so point number a is not marked here. I will basically mark it here consider point number a is here. Point number a has nothing to do with the activity, nothing to do with the job. It is basically a point here in this curve. And this point b is there. So you can basically use any other alphabets to note that. So what is important is that consider point number a.

Point number a means because it is where you will basically try to go on the cost concepts corresponding to the fact that you have been able to reduce the time. So you will ask a question and this is for each and every activity, not collectively. So if you consider the overall a normal work going on. So the normal cost is here, and the normal time duration is here.

So if you consider the overall project or the set of activities, the total cost comes out to be as given in point number b. Now you want to basically reduce the number of days so the reduction of the number of days is consider this is t2 and this is t1. So you would reduce it from t2 to t1 but the cost concept which was basically initially c2 has to basically increase to c1.

So what you are interested to find out is that what is the rate of change of this cost such that if you are decreasing the cost from ten to five days, so there is a five days of reduction. So you will try to find out that what is the overall cost implication from that project for those five number of days. So if you know per day increasing cost is hundred rupees, so it will be five into hundred but the things are not that simple. Reason is, I will give you two broad reasons which would make sense.

Number one is that, the cost concept which you seeing here in the graph is linear, in our case is not linear in the practical sense. It can be non-linear so actually it would happen is that more you crash it, more number amount of materials, man and financial resource have to be used. So it will be increasing on higher quantum as you reduce the number of days, that is number one. Number of point two is that remember when I did mention about trying to find out the variances.

We did mention time and again that we consider the jobs or the activities or the task are independent on each other such that trying to find out the variance by adding up the variances of all the activities which is there on the critical path, holds true. But that may not be the case because they would be interdependence between the activities or the jobs.

So those two are the main important point which needs to be assumed not to be true, based on which we are trying to basically proceed and solve the problem. But that will give you the way we try to basically tackle or what I discuss would definitely give you a much better feel that how it can be done for non-linear costs also.

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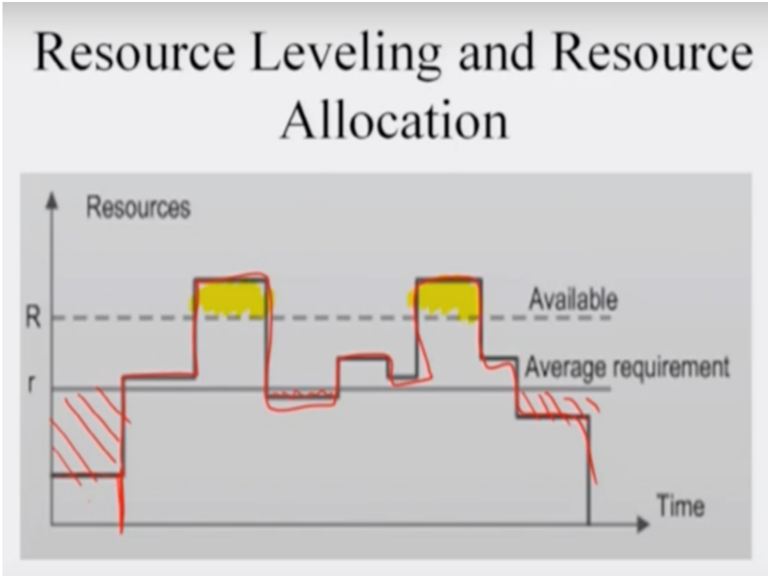

Now what, the graph which you have in front of you which is the three sixty-fourth slide is basically gives the resource leveling and resource allocation graph. So again, I have on the along the x-axis I have the time. So when you are trying to finish the time. And on the y-axis, rather than the cost, I am trying to basically draw the resources. Now, resources what I have marked is that there are two points.

So these two points are just to give you a feel that what is the maximum and minimum amount of resources which you can utilize. And it does not mention anything about the early start and the early finish or the late start and the late finish. So that would also come into the picture. So even though the I would not be discussing this with the graph, but I will try to basically dictate to you tell to you such that you appreciate that how things be can become complicated as you bring all more practical situations into consideration.

So if you see the y-axis, there are two points capital r and small r. Capital r is the maximum amount of resources you can use for any activity or the set of the jobs which are there at hand. Consider you have ten different excavating machines, or in the factory you have three different CNC machines. You cannot utilize more than three or consider you have about hundred different type of skilled laborers who are there in the factory.

Or, say for example, consider the you have number of lorries which you have to transport material from your um eh from your godown to the actual site is, say for example, twenty in number. So this capital r is that number, which I am talking about. And also consider that small r is the total number and minimum number of resources which you can use. So, I will just give you an example.

Say for example, you and the total number of workers which you which I did mention just few seconds back. Consider in a factory there are ten number of actual permanent labor, the rest are all temporary staff. And due to some reason you cannot fire those for those permanent labors. Which means that the total number of resources which you can use from the labor point of view is ten.

So this capital r and small r basically gives you the maximum amount of resources, any resource which you can use. And small r is the minimum number of resources you can use, point one. Point number two is that, the resources which you the graph which you have in front of you is not the combination of all the resources.

It is basically, if you want to go in a micro level, it would be the resources collectively. Collectively in the sense, manpower as a resource and you try to basically find out that what is the uses of manpower throughout the project, with time being noted down on the x-axis. Or, resources can be number of lorries which you have.

Resources can be number of CNC machines which you have. Resources can be number of computer which you have. Whatever it is, or resources can be number of design engineers you have. So if you see this graph, and the graph there is a sort of step function which you have. Where, I am trying to basically move my pointer. It basically means that the resource usage is in such a way that you will basically have two areas which needs to be taken care of.

The first area which I am now highlighting with my yellow highlighter, is the set of areas, at some point of time where you think you will be utilizing more than the required maximum amount of resources. And, if you see the other part, which I am now going to hash use the red color, are these portions, where my utilization of resources are below normal.

So consider this case. I am only concentrating on the CNC machines. Consider that arbitrarily and my resources are the CNC machines. So if I see the yellow part, it may mean that I may have to basically offload some of my work to a vendor who has that type of CNC machines, and who can give me the services for the project which I am trying to implement.

So there the overall cost which I need to basically utilize in order to offload that quantum of work to the vendor, can be found out for those portion which is marked in yellow felt pen here, or yellow color here. Such that, I can try to find out that if I offload that work to that vendor, what is my cost?

And also consider that if I am trying to crash the job and try to find out get the best benefit whether I am able to offset that overall cost by giving it to the vendor by the overall incremental profit which I am going to make. If that is true, obviously I will go for that. So consider now the second point which is the red hashed area.

So red hashed area which I have in front of me would be consider, not the CNC machine, is then the laborer, for the time being. And I am only concentrate on underutilization of resources. So if I think that the number of workers needed in a certain period of time, which is in the beginning of the project, is very low, what I will do is that, I would not hire those temporary workers then.

I will basically start hiring the temporary workers after a certain stipulated date. Such that I do not have to pay any extra amount of salary or any remuneration to those set of people, who I will basically hire later on. Such that I am able to offset the extra amount of cost, with respect to the respective profit I am going to make. So these two example even though they are very simplistic in nature, would give you an idea that how the overall resource allocation graph would be utilized for each and every resources for the project.

All considering time is there along the x-axis such that I can make a one-to-one comparison whether a resource is I have to basically hire or whether the resources which I have to have on in my case and I want to reduce it. I can offload temporarily such that I am able to balance the extra cost with respect to the profit which I in intend to make by crashing the jobs.

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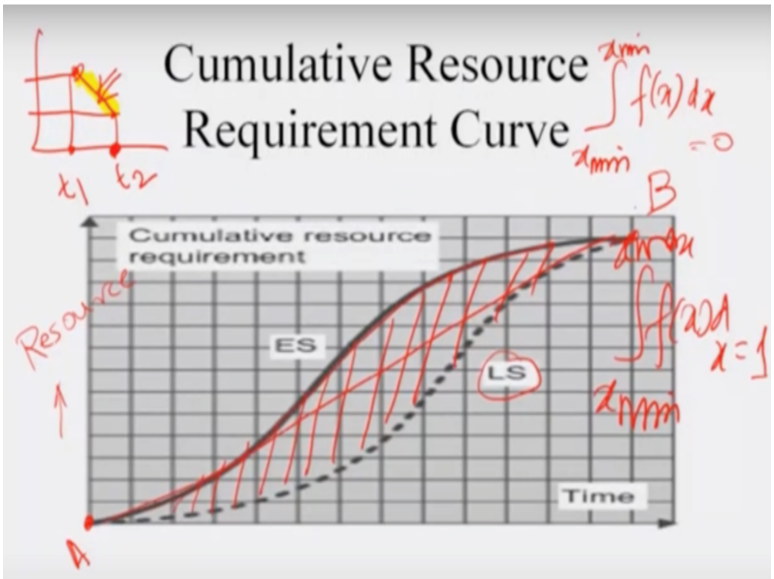

Now in the same way, the graph which we just discussed in the three sixty-fourth slide, let us consider along with the three sixty-fifth slide which is there in front of us. It gives us the cumulative resource requirement curve. Now if you do remember and have paid attention when I was discussing that three sixty-fourth slide, I did mention that this is resource allocation graph for any resource or with respect to time.

Now, those type of resource allocation graph can be made for the early start and the late start concept also. So, now coming back to the early start or late start if you remember, when I am trying to find out use the concept of forward pass method and the backward pass method and based on that I used the concept of early start and the late start. And then tried to balance and tried to find out what is the total float and the free float.

I did find out that to total float and free float as you would immediately say that it would be non-zero for those non-critical activities and zero for the critical activities. Now if I am able to draw the early start and the late start, total cumulative resources for any resource, that will give me in a way that what is the gap which is happening or extra utilization or less utilization of the resource which would happen.

If I try to combine both the concept of the early start and the late start for any activity or combination of the set of activities which are there in front of me. So now let us consider the usage and try to discuss in a very simplistic sense how this early start and the late start cumulative resource allocation can be utilized? So now, two important point along this y-axis, I have the total resource requirement.

So let us mention it resource so resource can, I am just mentioning in a very simple way as I discussed in the three sixty-fourth slide, was basically utilization of man, utilization of machinery, utilization of vendor, utilization of dumper trucks, utilization of say for example cranes, whatever it is. I am just discussing from a production point of view or a construction point of view.

Now if you see the bold line which is the early start cost, it basically starts at point zero which is a I am marking here and it ends at basically at point b which is the top most part. Now if you consider the late start also, late start also starts at a and ends at b. So, even though it would not make much sense but I am trying to basically draw a parallel which these graphs with the cumulative distribution graph which you see in probability.

So the cumulative distribution graphs basically starts from a point of zero, where the overall sum of the probabilities at x, its minimum value, is zero. And it goes, and increasing till the maximum value which is as you always know, should be one. So what we have is this. Considering discrete or continuous that does not matter for the distribution. So for the value of x minimum till x minimum if I add up f of x dx.

This f of x dx is the pdf for this distribution. This value is zero, which is this point that means I am not trying to utilize any sum add the sums of the probabilities. So the here the resources allocation utilization is zero. And if I add up all the probabilities which is from x minimum to x maximum, so f of x dx is basically 1 so which is point number b.

Now the area which you have in between, would give you in a nutshell the overall utilization and less of utilization of the resources. Which you would basically incur considering the early start and the late start concept which is there. Technically, you would always try to go thru a concept where the linear graph is used. If you remember the cost structure, I remember from the crashing point, if you see and if you can remember.

This is the crash point this is the normal point, and these are the times. For the normal time, this is the time which I mentioned as t2. This is the time which is basically t1 and this cost is given, so I am considering where I am highlighting. So let me highlight using the highlighter.

So this part was linear so if it is linear, what actually I would try to do is that, try to find out the best fit line between point a and b.

Such that the overall cost implication is as linear as possible. Such that I have an idea that what is the marginal rate of increase and decrease of the cost for the project. Such that I can utilize resources in the best possible manner, considering the early start and the late start concept. Now I will pause here and give you some more details.

If you remember the concept of PERT or the CPM, critical path method, I did mention four different ways of trying to basically align the jobs of the activities. One was basically end to start. That means ending of a, a being the previous job b being the later job. So, as a ends, b starts, so there is a number of day which is there and that is concept based on which we drew and solved all the problems for PERT and CPM.

Another concept which were are the three concepts, which are apart and parcel of general project scheduling and project management. But we did not consider, but we did mention that how the calculations can be done was basically the end to end. Which was if you refer to the slides will the diagrams you will understand one basically was from start to start that means the first start I am saying is basically for a and the second start is for b.

And another was basically from start to end so start being for and end being for b. So these three different ways of trying to analyze the jobs were not considering in the calculation for the PERT CPM we only considered the end to start. So the graph which you have in front of you, in the three sixty-fifth slide considered the early start and the late start concept.

Considering that the jobs, one job b, can only start after job is finished. So if you basically consider all the four concept in the picture, you could have different ways of trying to interpret how the cumulative resource requirement curves and how the crashing concept can be considered in a very simplistic manner.

Even though complications would be there if the number of jobs is very high but it will give you an idea that where the crashing where the extra resources can be utilized? Or where the less requirement of the resources are such that you can plan your activities accordingly.

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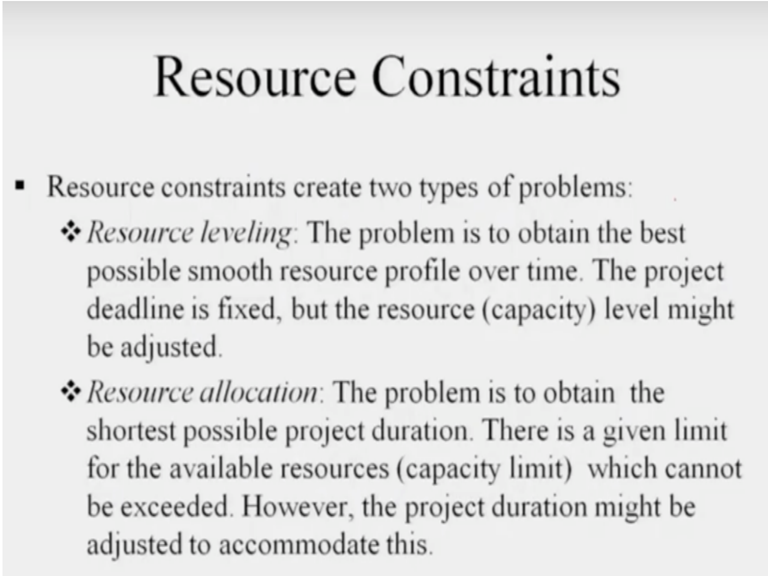

So resource constraints creates two types of problems, resource leveling. So you have to level the resources because any extra amount of requirement of resources or below the requirement resources on an average entails a cost. As I mentioned, extra amount of resources means you have to offloading to the vendor lesser requirements would be that it may be possible that those are permanent workers. I did not mention about the permanent workers, I just told about contractual workers.

The permanent workers have to be just kept sitting idle, such that you have to pay their salary, pay their benefits whatever it is till you are not getting the benefit or the work from them. So resource leveling has to be done. The problem is to obtain the best possible smooth resource profile over time such that and this is what it means.

The project deadline is fixed, so hence you have to basically adjust the resources in the smooth way. But the resource capacity level might be adjusted in order to meet the deadline in the best possible manner. Resource allocation as which has to be done so the problem is to obtain the shortest possible project duration considering the crashing and all these things are possible.

So there is a given limit for the available resources. So because there is a capacity limit. So all this work which you are doing based on the fact that you want to find out critical path does not assume that resources are a constraint. But if you bring that into the picture then these realities really slowly seep in. Such that there is capacity limit which cannot be exceeded. However, the project duration might be adjusted to co accommodate this fact into the picture.

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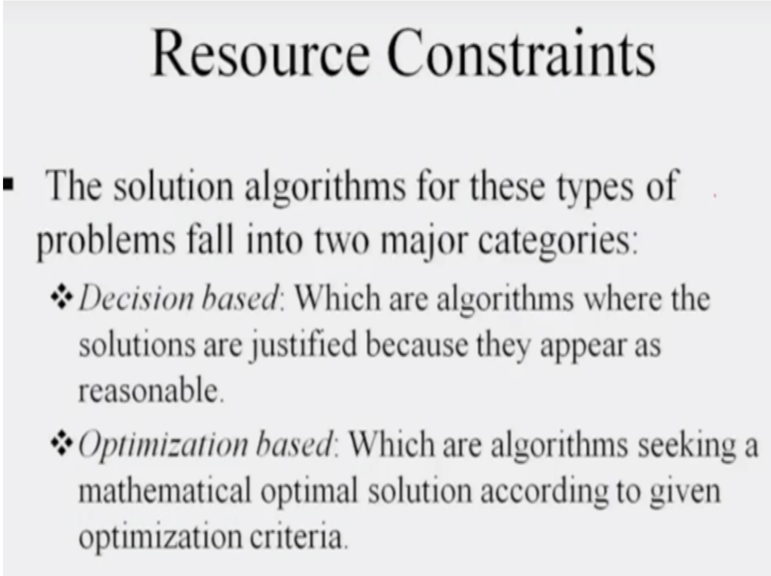

The solution algorithms for these types of problems fall under two main categories. One is decision based, which are algorithms where the solutions are justified because they are appear as reasonable. So what solution of the of the algorithm which you have for one problem, depending on the concept that it is the end to start, for the idea how the jobs and the activities are placed, may not be applicable for the case when you have the end to end concept being utilized.

So you have to be very careful that what algorithms you use. There are a whole bunch of algorithms. I cannot promise that I will be able to finish everything but I will try to give you an idea about that. And another are the optimization based, where the algorithms which are algorithms seeking a mathematical optimal solutions according to given optimization criteria or the set of such constraints which you have.

So if you are able to solve a certain optimization problem, so those sets of problems which have the similar properties can all also be solved using the optimization techniques which you may be tempted to use.

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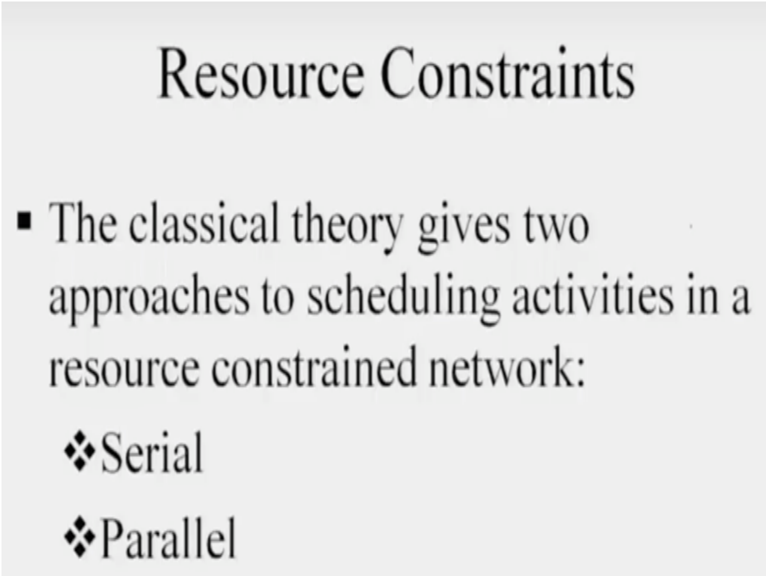

The classical theory gives us two approaches to scheduling activities in a resource constrained network. One is the serial concept, one is the parallel concept.

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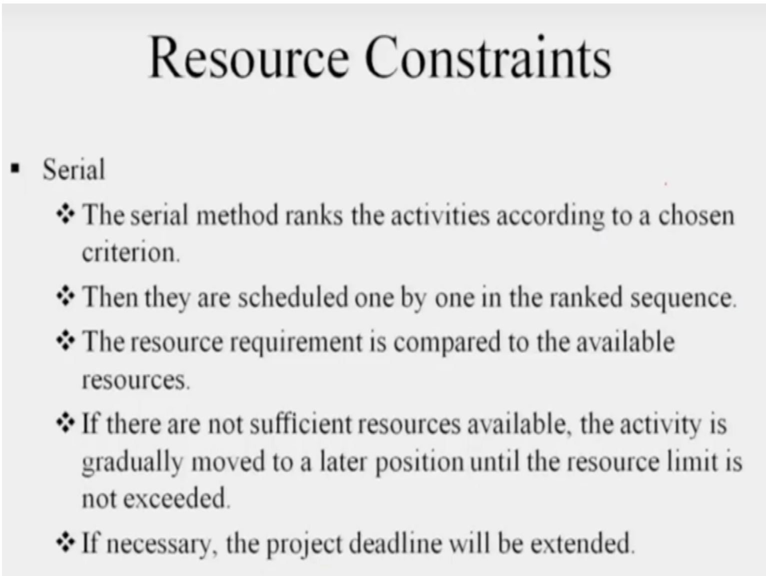

So in the serial concept, the serial method ranks the activities according to a chosen criteria. So whatever the criteria is whether the cost are very high, cost are very low, whether they have sophistication of technology is very high, or the sophistication of technology is very low or whether the weather conditions are such that you have to basically take that into consideration.

Whatever they are you basically you rank them, the activities according to those set of criteria which is there, or set of such decision variables which are there. So after that you schedule those activities one by one in the ranked sequence so consider you have ten different CNC machines, and the jobs are ranked. I am just using the very simple concept of a, b, c, d. So first you will basically utilize it for a.

Then depending on whatever resources are left you will basically come and utilize those resources which are the CNC machine for job b and so on and so forth, go accordingly. The resource requirements is compared to the available resources. So what you will try to do is that first try to use the small concept of trying to basically rank them from the highest priority to lowest priority. And utilize the resources accordingly.

And then try to see whether that is physically possible. So if you think that the resources are to be utilized for the CNC machines for job a, b, c, it may so happen that if you try to utilize for c, the resources are all exhausted. Or say for example, it may be possible that the materials are not available. In the sense some very specific tool which you are trying to utilize for this CNC machine that may not be available.

So in the practical sense, you have to basically understand those concepts accordingly. So if there are not sufficient resources available, as I just mentioned, the activity is gradually moved to a later positions until the resource limit is not existent and planed accordingly. So if you see the resource utilization; so there were some peeks which was over and above capital r. There were some values below small r.

So what I am trying to concentrate is that, what are the areas which are above capital r and basically you will try to analyze your problem accordingly. So if necessary, the project deadline may be required to be extended, such that you will be able to solve the problems accordingly, in a practical sense.

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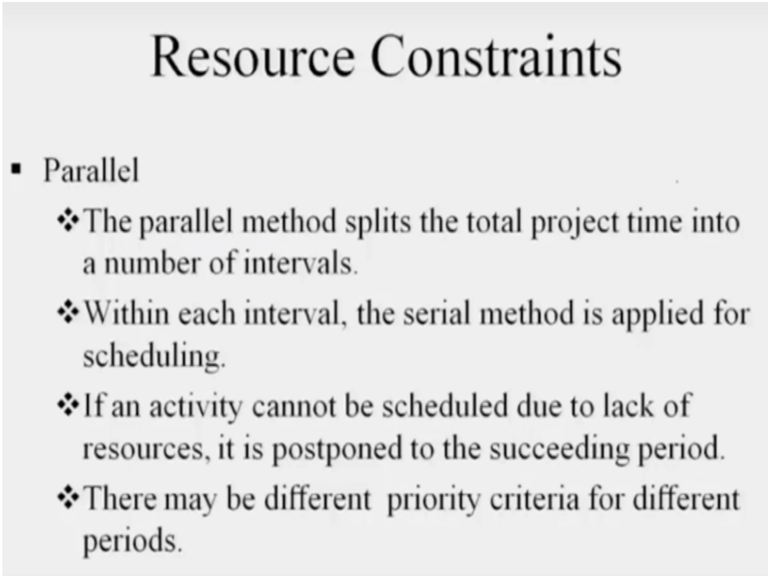

In the parallel concept, the parallel method splits the total project time into number of intervals. So basically divide the overall job into some intervals depending on what you think is important. Where you want can take a decision based on the past work which has been done, and then relook at your strategy and trying to basically analyze the resource allocations and the resource utilization.

Because, your main one criteria would be, you need to crash to jobs due to whatever reasons, as I mentioned. And you want to basically level the resources in such a way the utilization is optimal and you are not under the jurisdiction where cost implications becomes very high, such that it eats into your profit motive.

Within each interval, the serial method is applied into the scheduling. So for you break it into job into timeframe, and them utilize the jobs in those intervals and see whether the resource allocations are exceeding or they are within limit. If an activity cannot be scheduled due to lack of resources, it is postponed to the succeeding period.

So in the same way as in the serial method, if resources allocations are exceeding you pass it onto the next level, and then see where the resources are available. In the same way, time slots are there in the parallel one you do the serial one for each part. If any part or any activity or job cannot be accommodated in one of the set of the parallel set of jobs, you pass it onto the next level.

But obviously keeping in mind what are the precedence concepts, whether the jobs are very necessary, or whether the later jobs would not become critical, all these things have to be considered. So there may be different priority criteria for different jobs, as I just mentioned. Like say for example if job d is very important before e and f can be you used or they can be started.

Obviously, priority has to be given to d in spite of the fact that c is be basically before d. So consider the sequence as c, d, e, and f following d, in whatever sequence it is. And then if I need to basically reschedule d it will have any huge impact on e and f. E and f can be say for example, I call for a special machine from a vendor.

So if e is delayed, I have to basically talk to the vendor and delay the delivery of this machines, very special machine by a certain number of days. Because if I get it beforehand obviously I have to entail a huge amount of cost.

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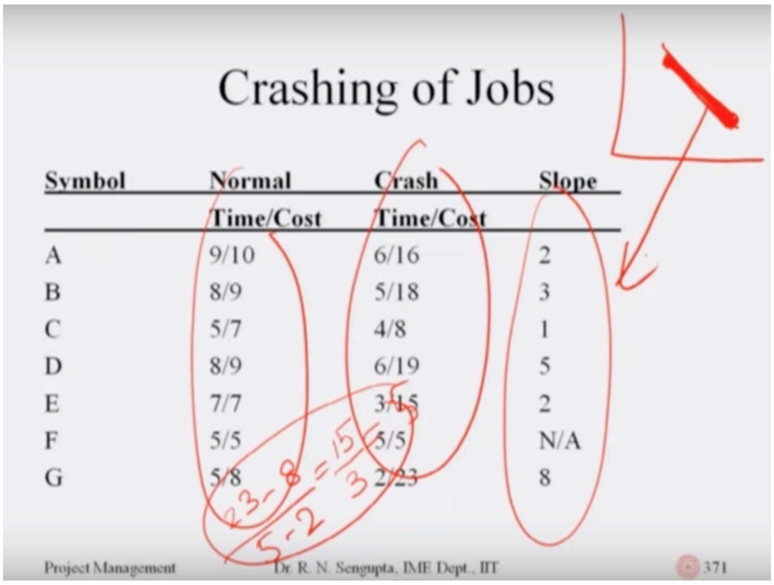
Crashing of Jobs

Symbol	Normal Time/Cost	Crash Time/Cost	Slope
A	9/10	6/16	2
B	8/9	5/18	3
C	5/7	4/8	1
D	8/9	6/19	5
E	7/7	3/15	2
F	5/5	5/5	N/A
G	5/8	2/23	8

So the crashing of the jobs, I will just give you a brief background of the problems which I am going to consider now in the thirty-first and the thirty-second so I will discuss the background of the problem. So the symbols are in the first column are a, b, c, d which are the jobs, whether you are doing the activity or no the activity or not, that does not matter.

The normal time of the costs are given, so you have basically, the normal time is nine for a you have nine and slash ten is the cost. So I am considering cost as linear; marginal rates are linear, not any non-liner function. Similarly for b it is 8, 9. So 8 and 9 is basically the time and the cost. Similarly for c it is 5, 7, d is 8, 9, e is 7, 7 f is 5, 5, g is 5, 8. And the crash time and the jobs are given, so which means that normal cost is for job a is ten, for a normal duration of nine.

And if I crash the job a, which is activity a to six days, the cost is basically sixteen. So I need to find out the slope, so the slope is calculated very simply 16 - 10 which is six divided by 9 minus 6 which is 3. So 6 divided by 3 is 2 if I go to the last one, let us go to the last one which is job d, it is twenty-three minus eight which is fifteen 23 - 8, let me write it down.

And the last is 5 - 2, which is basically oh so here, it is should be 5. So, I will just recalculate it. Anyway, I will try to basically have a look in this three seventy-one slide and come to that. So let me continue so this slopes are basically means there are marginal linear which are fixed, they are not non-linear.

So the slope which you have which is in the last column, the normal cost and the crash cost and the time are accordingly given here. So this is the crash point, this is the normal point. The slopes which I am talking about which I am highlighting time and again here is these values which are given. So with this background, I will close this class, and continue with the thirty-first class later on.

But before that I will again in the thirty-first class, I will again discuss this slide, and continue with the discussion how you basically simply tackle the concept of crashing of jobs and resource allocation from a very simplistic point of view. And obviously it will give a good idea, how it can be done on a practical sense. Have a nice day and thank you very much.