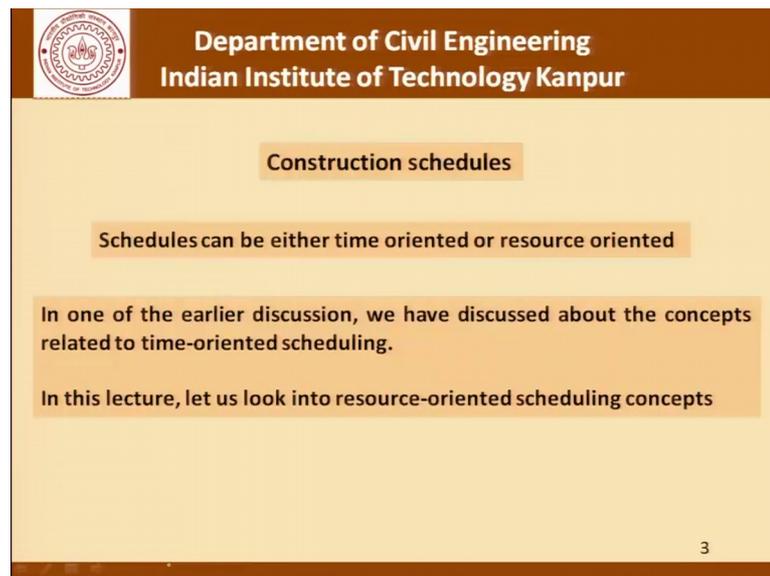


Principles of Construction Management
Prof. Sudhir Misra
Department of Civil Engineering
Indian Institute of Technology, Kanpur

Lecture - 19
Resource leveling and allocation

[FL] and welcome back to this series of lectures on principles of construction management, and in the last couple of lectures we have been talking about planning and scheduling in construction projects. Today we will concentrate on what is called resource leveling and allocation. Now construction schedules as we know are either time oriented or they can be resource oriented.

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Construction schedules

Schedules can be either time oriented or resource oriented

In one of the earlier discussion, we have discussed about the concepts related to time-oriented scheduling.

In this lecture, let us look into resource-oriented scheduling concepts

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In our discussion so far we have mostly talked about concepts related to time oriented scheduling. Today of course, as I have mentioned we will talk about resource allocation resource leveling and those concepts which are resource oriented scheduling concepts.

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Resource scheduling

- Estimation of activity times and the project duration using network diagrams assuming that there is an unlimited availability of resources.
- Real-life projects faces the resource constraints such as:-
 - Shortage of resources
 - Delayed delivery
 - Competing demands
 -
- Resource planning and allocation plays an important role in managing the construction projects.

4

Now, what is resource scheduling? Estimation of activity times and project durations using network diagrams assuming that there is no cap or there is no constraint on the availability of resources that is what we have been doing. If you recall those in earlier example we are probably going to do it again today that we estimate the quantum of work have a number for the productivity of the labour or equipment and try to come up with the time that is required to complete that activity.

So, we almost assume that there is no constraint on the availability of the resources as such, but in real life projects there are resource constraints such as shortage, delayed delivery, competing demands it may happen that you may have a set of resources, but there are different activities in the project which demand the use of that resource. You may have only 10 laborers or 10 workers and there may be 5 activities which demand labour or demand workers to complete them. We have to decide as construction managers which activities would take precedence over the others and so on. So, there are various situations because of which we need to do resource allocation we have to decide or prioritize, which activities will be taken up first, which may be postponed to a later time.

Resource planning and allocation plays an important role in managing construction projects.

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Let us look the principles involved in deploying resources to activities in a project, and the resulting implications through a simple illustrative example.

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Now, let us look at the principles involved in deploying resources to activities in a project and the resulting implications through a very simple illustrative example.

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Consider a project that activities A to D, with precedence relationships, and workload of individual activities as shown below.

Activity	Precedence	Man-days
A	NONE	500 ✓
B	NONE	200 ✓
C	A ✓	300 ✓
D	B ✓	200 ✓

Also, assume that activities A and C require labor of similar expertise (T1), and activities B and D require labor of another expertise (T2).

- (1) Determine the project duration, if 10 no's of T1 labor and 10 no's of T2 labor are employed for the project, and,
- (2) Comment on the resource deployment.

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We have talked of this project before when we considered a simple project having just the activities A B C and D with precedences as given A and B are independent and can be started right at the word go C depends on A and D depends on B this is the man days requirement as far as each of these activities is concerned. Now we also said that A and C require labor of similar expertise.

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To begin with, 10 labor with T1 expertise and 10 labor with T2 expertise are allocated to activities A and B.
After completing A and B, same numbers of T1 and T2 labor are allocated to activities C and D respectively.

The duration of each activity can be calculated based on the number of labor allocated to these activities.

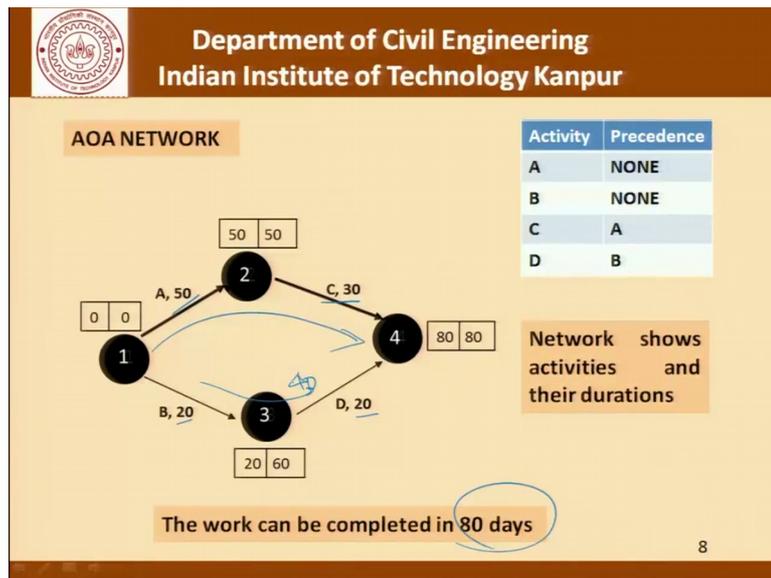
Activity	Precedence	Man-days	Expertise	No. of labor	Time (days)
A	NONE	500	T1	10	50
B	NONE	200	T2	10	20
C	A	300	T1	10	30
D	B	200	T2	10	20

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Let us say T 1 and B and D require labor of another expertise which is T 2. What we tried to talk about was that if we allocate let us say 10 numbers of T 1 expertise labor and 10 numbers of T 2 expertise labor how will the project planning be done. Now once we assume that there are 10 workers with T 1 expertise available to us 10 workers of T 2 expertise available to us, we can find out that the time required to complete this project is 50 days for activity A 20 days for activity B 30 days for C and 20 days for D. This is nothing but this number here which is man days divided by the number of laborers.

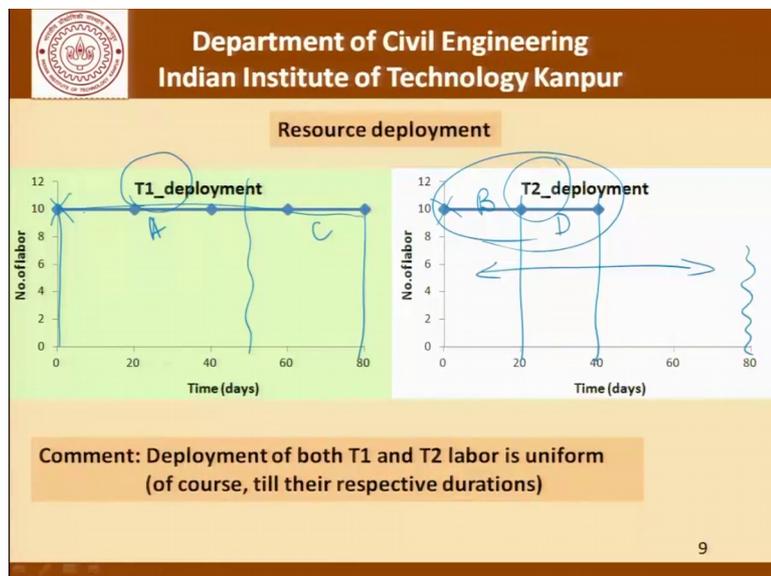
Now, what this assumes is that the labor supply or the availability of labor whether it is T 1 or T 2 is constant over the entire duration of the project.

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Representing this project on an activities on arrow network, we can find out that if A is done in 50 days C is done in 30 days B is done is 20 and 20; the earliest that the project can be completed is 80 days because this path is now the critical path. This can be done in 40 days.

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In this representation What we have assumed is that as far as the labor with T 1 expertise is concerned as far as the labor with T 2 expertise is concerned both of them are employed to the fullest extent right from the word go till the project is completed. So, 10

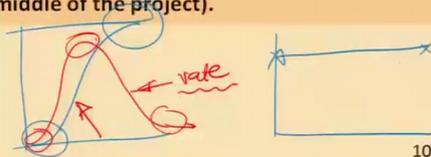
numbers of workers with T 1 expertise work from day 1 to day 80 even the project is completed initially for some time they work on activity A and then they work on activity C. In this case we have assumed that the activity B starts at the earliest that it can and these people who have an expertise in T 2 work initially on B and then on D and then everybody goes home.

This part of course, can actually be completed not necessarily starting with 0, but anywhere in this region provided it is not going beyond the 80 day limit when A and C will get completed. Now this approach which assumes a constant deployment of labor has its own problems.

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- However in an actual situations, uniform availability of the resource is perhaps neither possible nor desirable.
- Moreover, it is not advisable too. Few obvious reasons could be:-
 - Mobilizing sufficient funds during the initial stages of construction may be not possible in most of the projects.
 - Most of the construction activities happen during middle stages of the project, and hence it is recommended to have gradual increase in the deployment of resource in initial stages, and a gradual decrease after meeting the peak demand (which essentially happens during the middle of the project).



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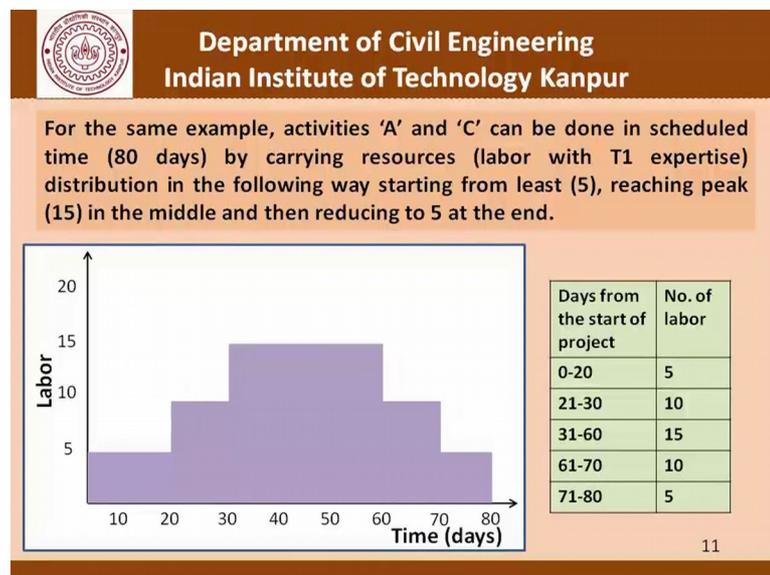
Uniform availability of resources is neither possible nor desirable; moreover it is not advisable as well. Few obvious reasons could be mobilizing sufficient funds during the initial stages of the project may not be possible in most projects. Most of the construction activities happen during the middle stages of project and hence it is recommended to have a gradual increase in the deployment of resources in the initial stages and gradually decrease it after meeting the peak demand which essentially happens during the middle of the project.

We have talked about the S curve. And it is relevance as far as project progress is concerned. There are lots of reasons why most projects follow this S curve. In the initial

part it is not only the mobilization of the funds, but it is also the learning experience availability of front all these kind of issues make it very difficult to achieve a progress which can be sustained all the time, but having done that additional experience of learning, it is much easier to gradually increase the resources reach a peak level and then (Refer Time: 06:56) it off

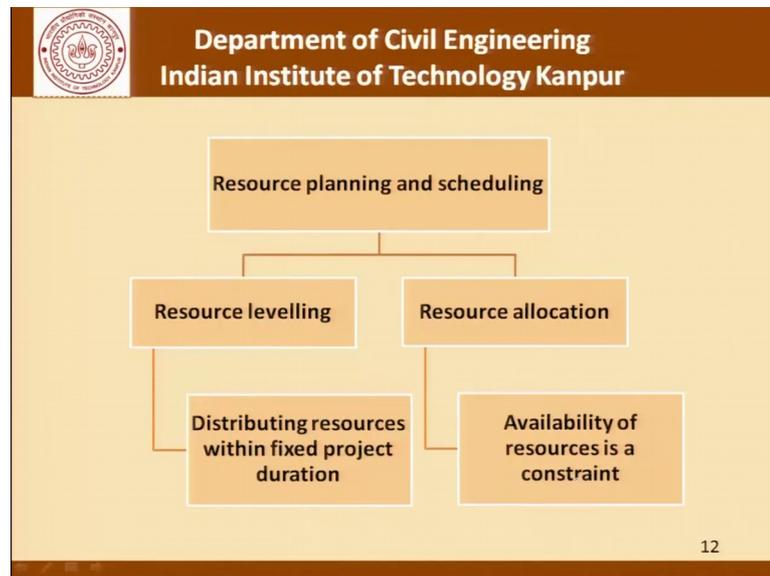
Similarly, towards the end of the project it is very difficult to have the entire work force working at that project. There will be a smaller and smaller areas which will be available, there will be smaller and smaller amounts of work which will be left. And therefore, it makes no sense it will be very difficult for a uniform progress to be maintained. What I am essentially saying is, if we differentiate this total progress with respect to time what we will get is a progress curve. So, this is our rate at which the project moves. And if the project moves gradually in the beginning reaches a peak at the middle stages of project and then goes to 0 once again, what we will get as the cumulative progress is what is given in blue. Now this is precisely the kind of deployment of labor that we would like to actually see rather than the constant deployment as we have seen in the previous slide.

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What this slide shows is an alternative way of having employed the labor for completing the 500 or 300 man days of work. It really shows the deployment at different points in time and the rest of it I am sure you can figure out.

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Now, coming to our main discussion today which is resource planning and scheduling; there are 2 aspects to our discussion, one is resource leveling and the other is resource allocation. Leveling deals with distribution of resources; within the fixed project duration and allocation deals with availability of resources under a constraint.

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RESOURCE LEVELLING

Resource levelling is the process of allocating resources among various activities such that the peak requirement of resources is reduced with a constraint on time.

Underlying assumptions in resource leveling are

- Only one type of resource is considered throughout the project.
- Activities already underway should be completed first.

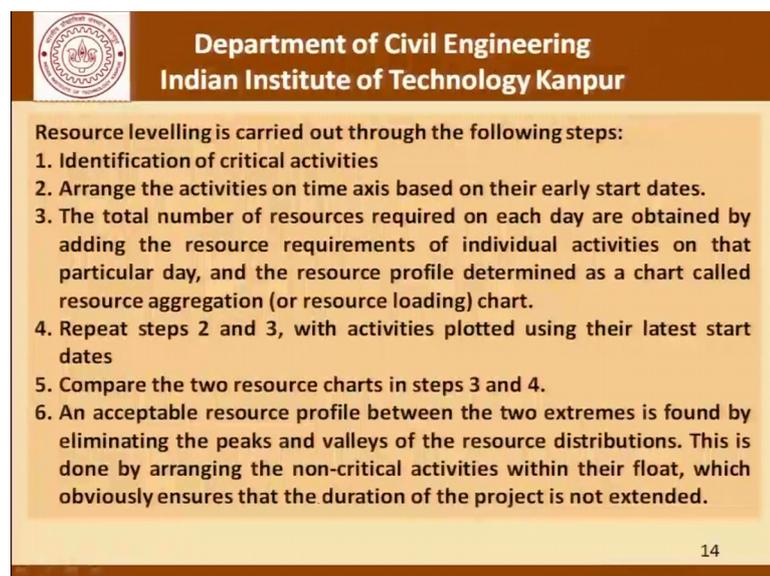
Activities — critical
ve.

So, coming to the first part which is resource leveling that is the process of allocating resources among various activities such that the peak requirement of resources is reduced

with a constraint on time and the underlying assumptions in resource leveling are only one type of resource is considered throughout the project. And activities already underway should be completed first. What I would like you to recall is that activities are of 2 types let us say critical activities and non critical activities. Critical activities are those which must follow one after another without any gap. Without any gap means there is no float. And at the completion of these critical activities the project is completed. So, basically the last activity to be completed has to be a critical activity that is by definition.

now along with the critical activities there is a set of non critical activities with whatever dependences they may have critical activities also have their dependence on non critical activities, but there is some float there is some (Refer Time: 09:53) independence in deciding when a non critical activity is done. So, the whole idea of resource leveling is to make sure that the resources that are used in non critical activities are not spread out over the project is sporadically. It should not happen that over a period of time I need a resource here then I need it here then I need it here. If possible I would like to build these resources such that they are used here and here So that this particular resource can be brought to site only for this duration and be let go. Provided of course, that this is for non critical activities, in the case of critical activities there is something which we may not be help much.

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Resource levelling is carried out through the following steps:

1. Identification of critical activities
2. Arrange the activities on time axis based on their early start dates.
3. The total number of resources required on each day are obtained by adding the resource requirements of individual activities on that particular day, and the resource profile determined as a chart called resource aggregation (or resource loading) chart.
4. Repeat steps 2 and 3, with activities plotted using their latest start dates
5. Compare the two resource charts in steps 3 and 4.
6. An acceptable resource profile between the two extremes is found by eliminating the peaks and valleys of the resource distributions. This is done by arranging the non-critical activities within their float, which obviously ensures that the duration of the project is not extended.

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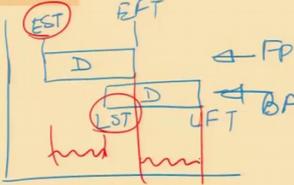
So, with this background in mind let us move forward and try to understand the steps involved in the resource leveling process. Identification of critical activities, arrangement of activities on the time axis based on their early state dates, determining the total number of resources required on each day by adding the resource requirements of individual activities planned for that day and the resource profile determined as a chart called the resource aggregation or resource loading chart.

As we do a simple example these things will become clear repeat steps 2 and 3 with activities being plotted using the latest start dates comparing the 2 resource charts that is that determined in step 3 and 4, and finding out an acceptable resource profile between the 2 extremes eliminating the peaks and values in the resource distribution. This is done by arranging non critical activities within their float which obviously, means that the duration of the project is not compromised.

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Let us understand the resource leveling concepts through an illustrative example.



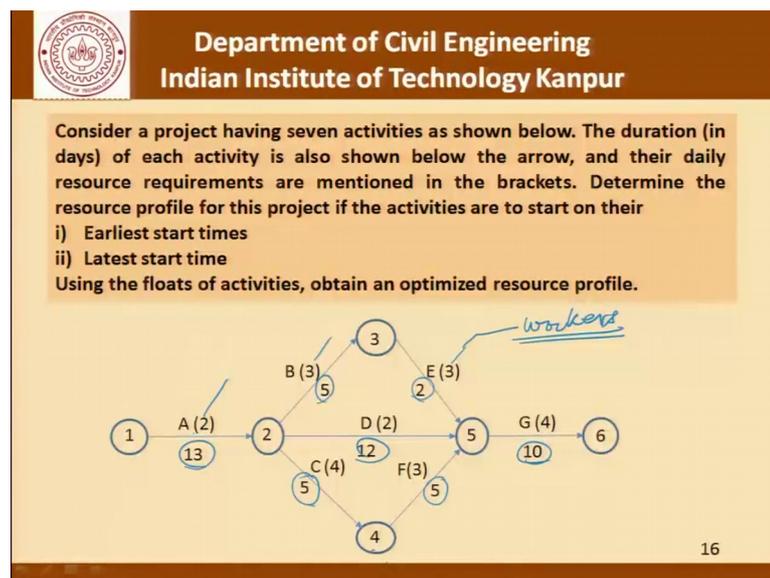
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Let us go through a simple example to understand this concept. Let me once again reiterate that what the steps essentially have told us is that a non critical activity can start and finish as is shown here; if this is my earliest starting date for that particular activity this is the duration of that activity this becomes my earliest finishing time for this activity; however, without compromising the duration of the project this activity can also

be scheduled in this time frame where the duration of the project remains the same and this is my last starting date.

Or the latest starting date this becomes my latest finishing date this we get from the backward pass and this is what we get from the forward pass. And remember that the activity can be scheduled anywhere between these 2 extremes that is within EST and LST if the activity starts anywhere in this region, it will get completed anywhere in this region and this will not compromise the length of the project. So, that is precisely the kind of thought process that goes on in leveling of resources. So, let us understand this a little bit better through this example which gives us the 7 activities as shown their dependences and I have already the network for you.

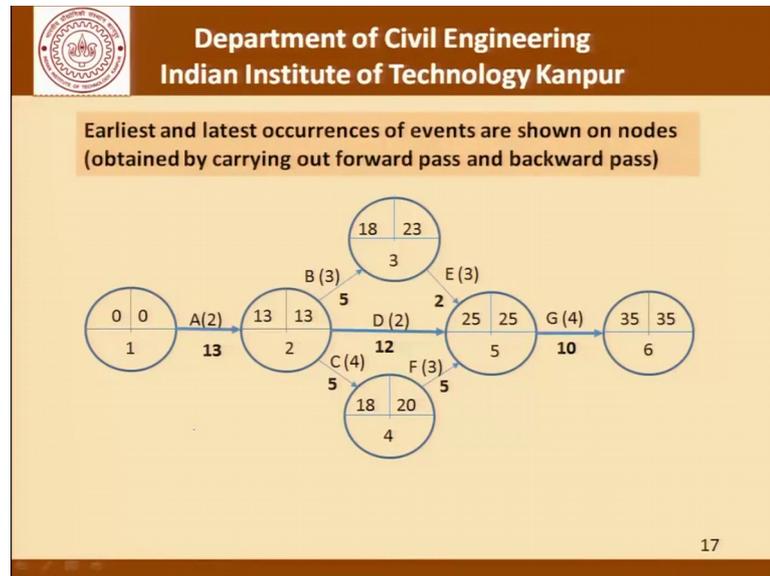
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So, this here is the durations of all these activities a requires 13 B requires 5 C requires 5 D requires 12 E requires 2 and F requires 5 let us say days to complete G requires 10 and this number here in the bracket is the resources. So, in this case as a simple example we are saying that this number here represents the number of workers which is required to complete this activity. We must remember that as far as this example is concerned we are also going to assume that a requires 2 workers means it requires a team of 2 workers. It cannot be done or it cannot be started unless there are 2 people available. Further it cannot be accelerated by putting more people on the activity.

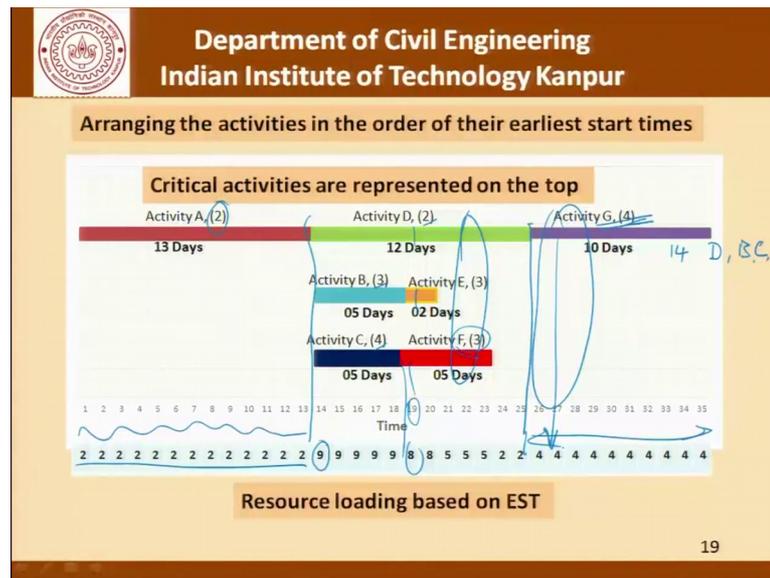
So, with this understanding and assumptions let us try to find out what can we do with the resource allocation algorithm which we have just learnt.

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So, the earliest and latest occurrence of the events are shown in the notes and they have been obtained by the forward pass and the backward pass I am sure you know how to do it, A can start at 0 and therefore, this node here which is node tow the earliest it can be reached is 13, this node 5 can be reached earliest depending upon the maximum of these 3 nodes which are converging on this and so on. So, we find out that activities A D and G are critical and the project duration is 35 days. So, this is the first step we find that A D and G are critical activities they are highlighted by a form arrow. And we find that the project can be completed in 35 days.

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Now let us try to do the next step which is scheduling these activities on the time axis. This representation schedules these activities in the earliest start times. So, A obviously, starts here finishes at 13 D which follows this is completed here G is completed here and this is 35 days. As far as B is concerned you will recall from the diagram that it depends on A and therefore, can be started as soon as A is completed and the same thing is valid for activity C.

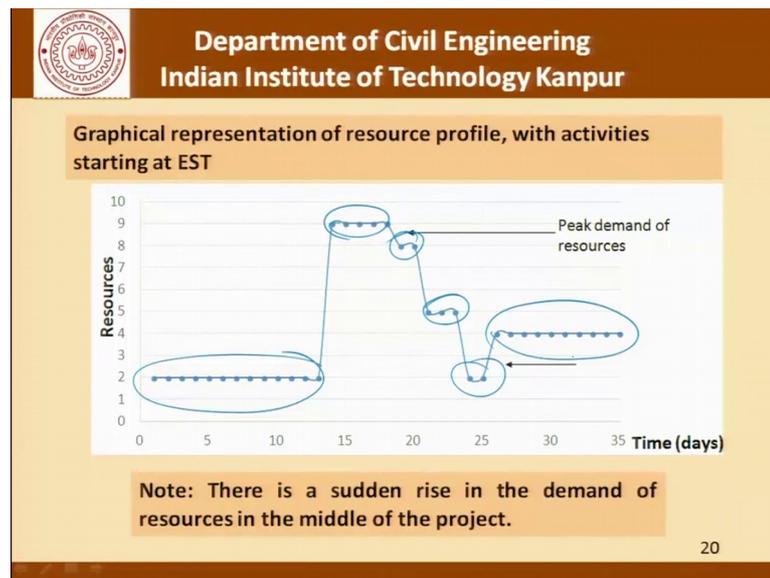
So, these activities start here on let us say 13 and are completed at whatever times depending on their durations and we reach these points as is shown here. Now on this if we superimpose what is the kind of resources that we need on each day. We find that as far as this point is concerned that is as far as the first 13 days are concerned only activity A can be done, no other activity can be done. Which means that A which needs a team of 2 persons is the only activity going on as far as this project is concerned and our deployment is only 2 workers.

Now coming to day 14 we have the possibility of activity D B and C being carried out. D requires 2 B requires 3 and C requires 4 workers and therefore, the deployment required as far day 14 is concerned is 9. This continues till such time as activity C is finished once C finishes we have activity F which may start and so on. What we need is to do find out on a given day what are the activities that are going on and find out what is the demand for the labor on that particular day. So, we find that beyond this point only activity G is

going on and that requires 4 people and that is what we have. So, towards the end of the project we have only people working on activity G right upto the end of the project.

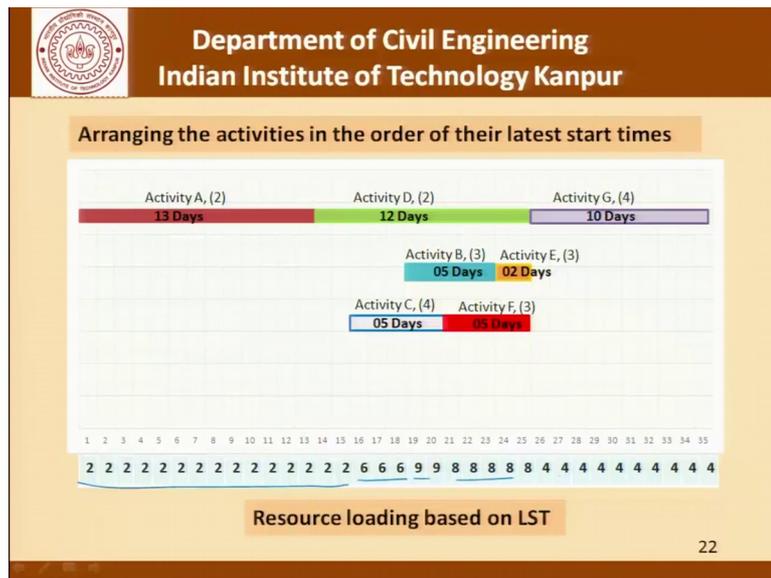
This is a scenario for starting all the activities on their earliest starting times. Now if we represent this labor deployment on the time axes.

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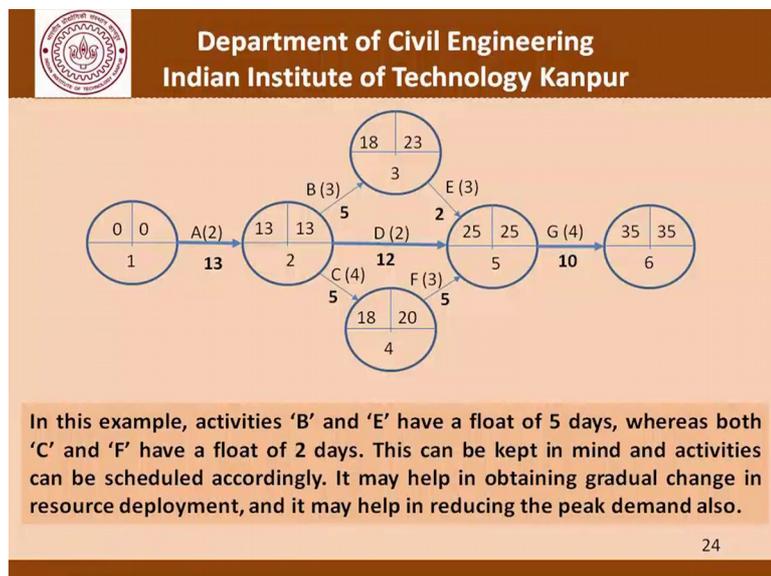
This is what we get. So, we have 2 people here increases to 9 here goes to 8 5 drops to 2 and then goes back to 4. What we have to see is whether this is the most desirable form of labor deployment or not. In order to be able to do that let us try something else.

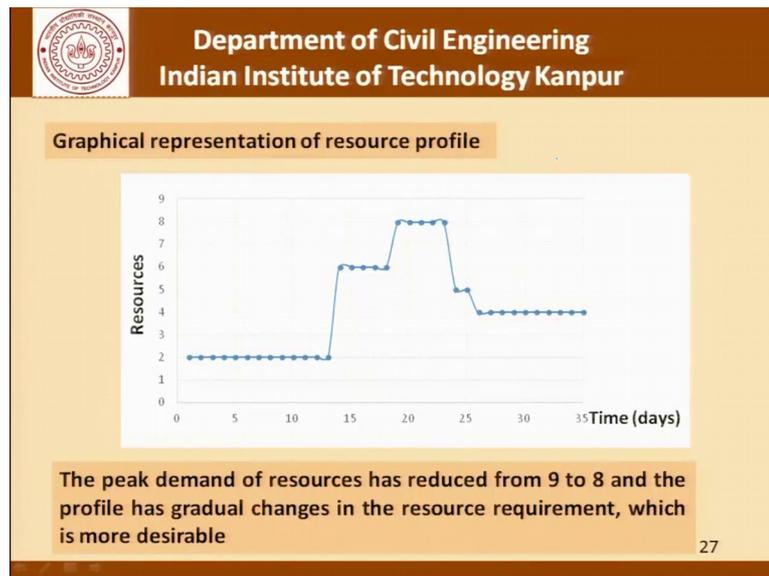
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Let us try to schedule the activities So that they start at their latest starting times. What we are trying to do is to ensure that G which is the last activity and depends on the completion of activity E and completion of activity F is not delayed, because this is my critical path. In order for this to happen we must make sure activity B starts here activity, E starts here, C starts here and F starts here. That is precisely what is their latest starting times. So now, with this algorithm or with this thought process let us try to then find out what is our labor deployment. This is what the numbers you will get from here to here it will be all 2's then it goes to 6 9 8 and goes back to 4.

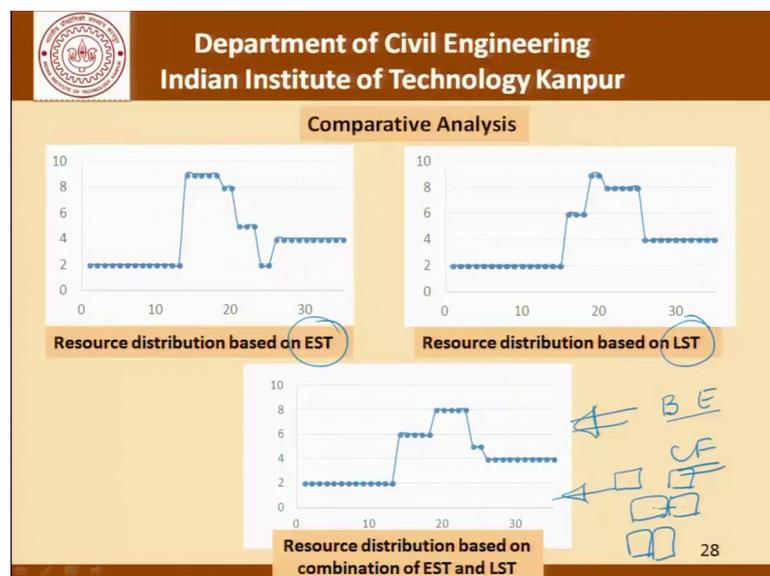
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This is the graphical representation of the resource profile that we get when we have chosen to start one set at the earliest starting times and one set at the latest starting times. Now before we compare these 3 resource curves I must point out that here we find that the peak demand of resources has reduced from 9 to 8.

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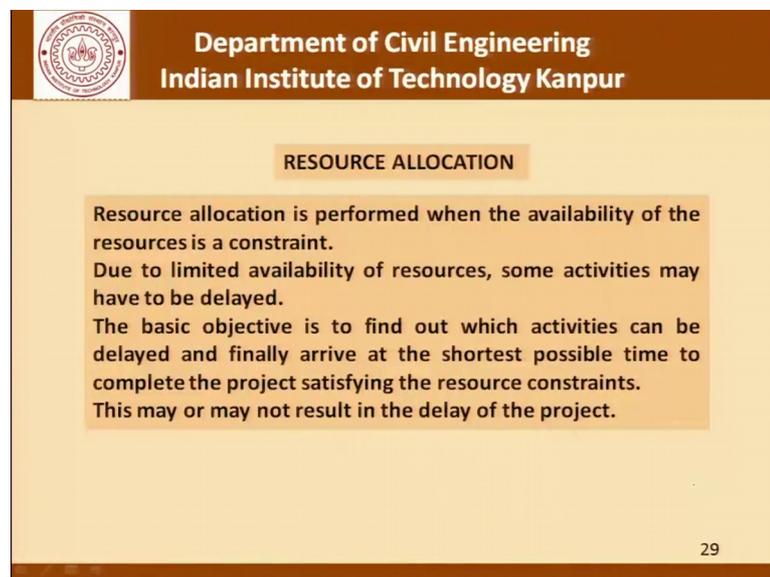


Now, this picture here shows the comparison that we have this was when the activity is started on their earliest starting times, this what we have when we have the activities starting at the latest starting times, and this is what we have when we did the

combination of EST and the LST for the different activities. Personally to me this seems to be the best alternative that we have So far we can try another you can work out more examples or more combinations with B E and C F separated. What we have done is B and E have been taken to both start at the same time B and E have followed each other C and F have followed each other, as soon as the previous one was completed. So, as soon as B was completed E was started as soon as C was completed F was started we can separate these 2 activities because we can say that B we will start at the earliest time and E we will start at the latest time.

So, if we do these kind of combinations we will probably be able to generate more resource aggregation curves and then make a judgment on which is the most desirable form. It may also be governed by availability and so on, and that is the next topic of discussion today that is allocations of resources under a constraint regime, now coming to the discussion on resource allocation under a constraint. The resource allocation is performed when the availability of resources is constraint.

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RESOURCE ALLOCATION

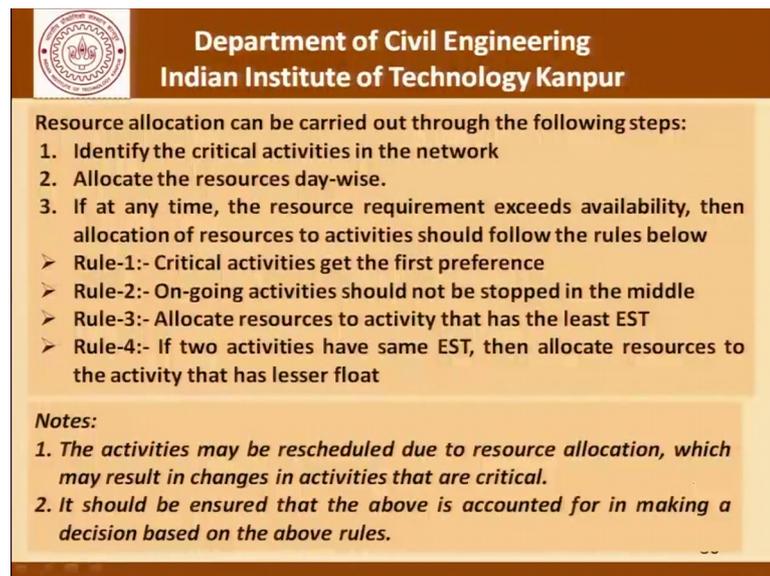
Resource allocation is performed when the availability of the resources is a constraint.
Due to limited availability of resources, some activities may have to be delayed.
The basic objective is to find out which activities can be delayed and finally arrive at the shortest possible time to complete the project satisfying the resource constraints.
This may or may not result in the delay of the project.

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due to limited availability of resources some activities have to be necessarily delayed. The basic objective is to find out which of the activities can be delayed and finally, arrive at the shortest possible time to complete the project satisfying the resource constraints. This may or may not result in the delay of the project.

In as much as we will try to ensure that the project is not delayed by finding out the critical activities, trying to make sure that the critical activities are not starved of resources at times it may become impossible to avoid, and that is something which we have to deal with and if we plan enough we are able to flag these issues in advance.

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Resource allocation can be carried out through the following steps:

1. Identify the critical activities in the network
2. Allocate the resources day-wise.
3. If at any time, the resource requirement exceeds availability, then allocation of resources to activities should follow the rules below
 - Rule-1:- Critical activities get the first preference
 - Rule-2:- On-going activities should not be stopped in the middle
 - Rule-3:- Allocate resources to activity that has the least EST
 - Rule-4:- If two activities have same EST, then allocate resources to the activity that has lesser float

Notes:

1. *The activities may be rescheduled due to resource allocation, which may result in changes in activities that are critical.*
2. *It should be ensured that the above is accounted for in making a decision based on the above rules.*

Now, as far as the steps which are involved in resource allocation these are the following, identify the critical activities in the network. Allocate resources day wise. If at any time the resource requirement exceeds availability then allocation of resources to activities should follow the following rules. Rule one resource allocation gets the first preference. Rule 2 ongoing activities should not be stopped in the middle. Rule 3 allocate resources to activities that have the least earliest starting time. And rule 4 if 2 activities have the same EST then allocate the resources to the activity that has a lesser float.

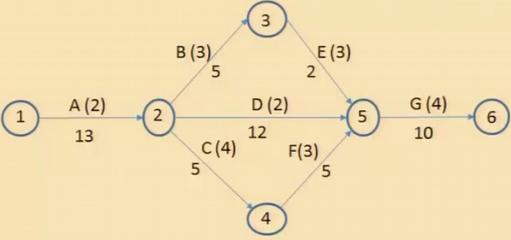
Please note that activities may be rescheduled due to resource allocation which may result in activities that become critical. Once we are playing around or shifting the non critical activities their starting points their scheduling that may lead to a change in the critical path. And that is something which has to be constantly kept in mind. It should be ensured that the above is accounted for in making a decision based on the above rules. This change in the critical activities should always be there as a governing principle when we are trying to do the reallocation of resources.

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ILLUSTRATIVE EXAMPLE

Let us consider the same example in which the project takes 35 days to complete normally. Assume that the maximum availability of resources on a given day is 8. Determine if there is any delay in the project completion.

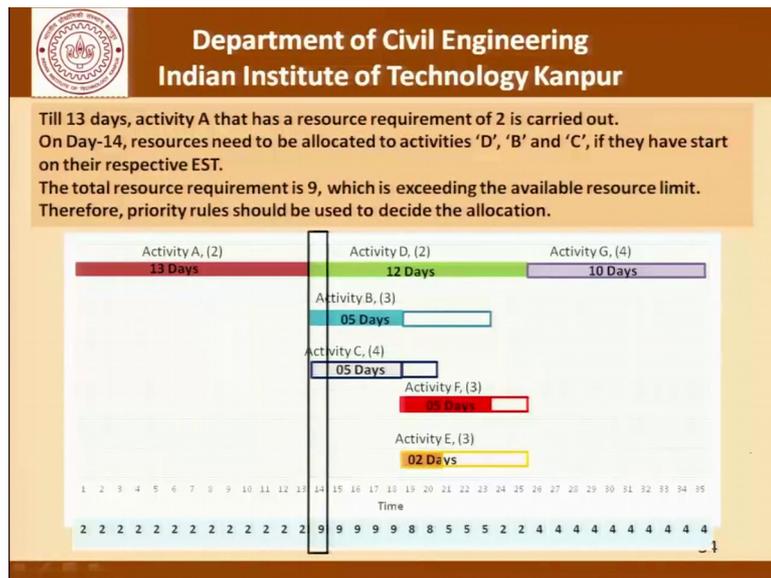


```
graph LR; 1((1)) -- "A (2)  
13" --> 2((2)); 2 -- "B (3)  
5" --> 3((3)); 2 -- "C (4)  
5" --> 4((4)); 3 -- "E (3)  
2" --> 5((5)); 4 -- "F (3)  
5" --> 5; 5 -- "D (2)  
12" --> 2; 5 -- "G (4)  
10" --> 6((6));
```

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Now, let us look at an illustrative example for this. Let us consider the same example and which the project takes 35 days to complete normally. Now we will assume that the maximum availability of resources on a given day is 8. So, recall that the maximum resources that we had in a lot of our simulations that we ran was 9. Determine if there is any delay in the project completion. Again we would carry out this first exercise and find out that A D and G are critical activities with the project duration of 35 days through the forward and the backward pass. Now this here shows a graphical representation of the activities is starting at EST with the float. The float is what we have added to the previous diagram and this is our resource aggregation diagram.

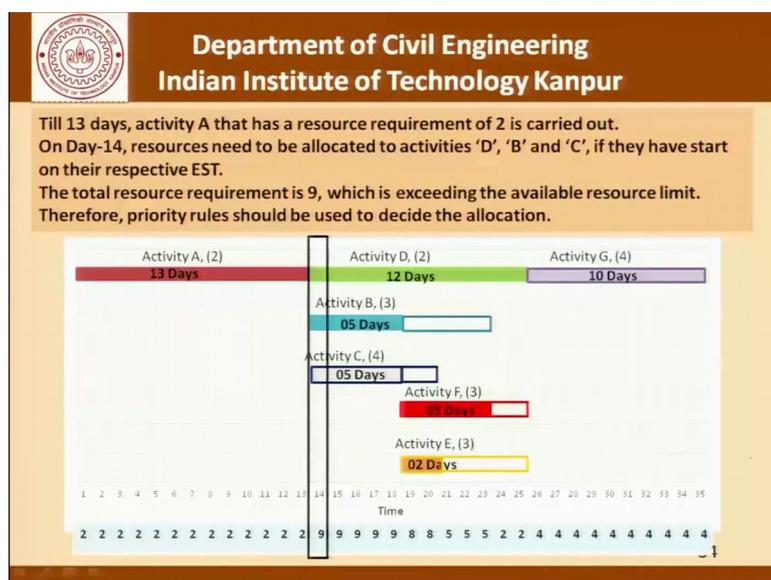
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and we note that till day 13 activity A that has a resource requirement of only 2 is carried out and that is not a problem because the maximum available resources is 8.

Now, on day 14; however, the resources need to be allocated to activities D B and C, if they have to start on their respective EST's. Now the total resource requirement on day 14 therefore, turns out to be 9 which is exceeding the available limit of 8. So, we have to find out which of these activities needs to be supported. How should the resources be allocated? And for that we go to the rules that we have just gone through.

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Day 19

Activities	Resource requirement	Critical Activity (Y/N)	On-Going	Earliest Start Time	Float	Priority
D	2	Y	Y	13	0	1st
B	3	N	N	13	5	2nd
E	3	N	N	18	5	4th
F	3	N	N	18	2	3rd

Therefore, activities 'D', 'B' and 'F' will be started (total resource requirement is 8).
And, activity 'E' is delayed .
Note that Activity 'B' has delayed by 5 days from its EST.

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We find that D B F and E is the ranking. D is on the top because it is a critical activity. The next is B because it has the earliest starting point. And between E and F, F is taking precedence because it has a lower float.

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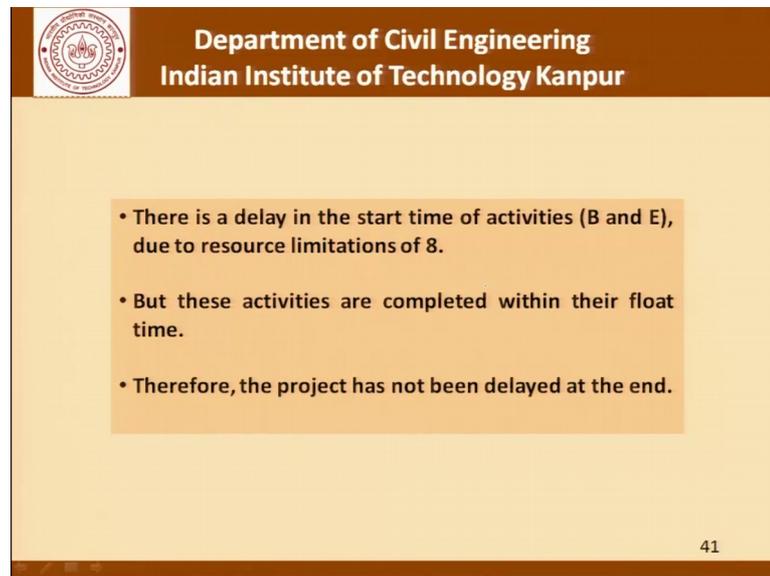
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- Same allocation of the resources shall be followed till activities 'B' and 'F' are completed.
- Therefore, on day 24 Activities 'D' and 'E' have total resource requirement of '5', which is within the permissible limit of the resources.
- Activity E, which is delayed shall be completed within its float.

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Now, this allocation of resources shall be followed till activities B and F are completed. And on day 24 activities D and E have a total resource requirement of 5, which is within the permissible limit. And therefore, activity E which was delayed, but it has also been completed within its float.

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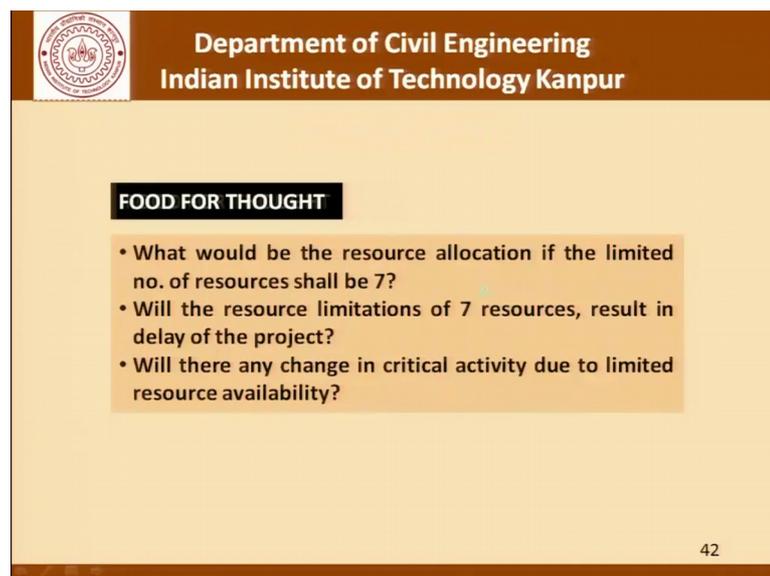
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- There is a delay in the start time of activities (B and E), due to resource limitations of 8.
- But these activities are completed within their float time.
- Therefore, the project has not been delayed at the end.

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So, what we have seen in this example is that there is a delay in the start of activities B and E due to the resource limitation of 8, but these activities are completed within their float time and the project has not been delayed at the end. Having done this example the way we did it.

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FOOD FOR THOUGHT

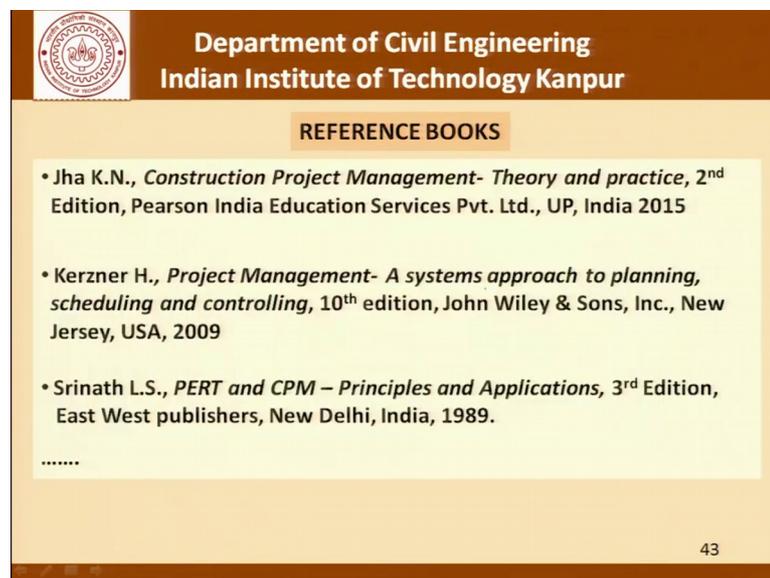
- What would be the resource allocation if the limited no. of resources shall be 7?
- Will the resource limitations of 7 resources, result in delay of the project?
- Will there any change in critical activity due to limited resource availability?

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Let me review with an assignment that would be the resource allocation if the limited number was 7. We worked with the example of 8. In fact, in our example when we did

the resource leveling at that time also in one of the iterations, we found that we could complete the project with the maximum allocation of 8 workers. I would like you to compare these 2 scenarios and do this exercise if the number was 7. Will the resource limitation of 7 result in a delay of the project? And finally, will there be any change in the critical activities due to this revised maximum on the available resources? These 3 questions are left to you as a food for thought we will try to come back and discuss them if possible at a later point in time.

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And here is the list of references as usual which will help you better understand the discussion that we have had today. And I will look forward to see you in a later class.

Thank you.