Project and Production Management
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Lecture – 14
Resource Profiles and Leveling

Today we will be talking about resource considerations in projects. In fact we have already dealt with cost which is a major resource and we have talked about time-cost tradeoffs which is one of the most commonly used methods of dealing with resources as far as costs are concerned. But today we will generalize our discussion to talk about resources in general and we will talk about resources like man power, machines and various other capital equipments which are necessary in the implementation of a project and we will see what kinds of special considerations are required to plan for various types of resources in a project. The first thing that we have to talk about is the construction of the resource profiles.

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You would recall that we can start with a project network and if we impose on the project network the activity times it is very convenient to determine a project schedule by doing a simple forward pass and a backward pass which can identify the early start and the late start schedules. This schedule when depicted as a Gantt chart would appear something like this. That means for each activity in the project we can identify the time that, that particular activity is going to be taking place. We can in fact establish this kind of schedule. It's quite likely that these individual activities apart from cost might require other resources for their implementation. These activities might require for instance man power. They might require some special type of machines. They might require some special equipment. If we want to find out the manner in which we are going to be using that equipment we will have to refer to these basic schedules. From the basic schedule of activities here we superimpose on this the activity resource data.

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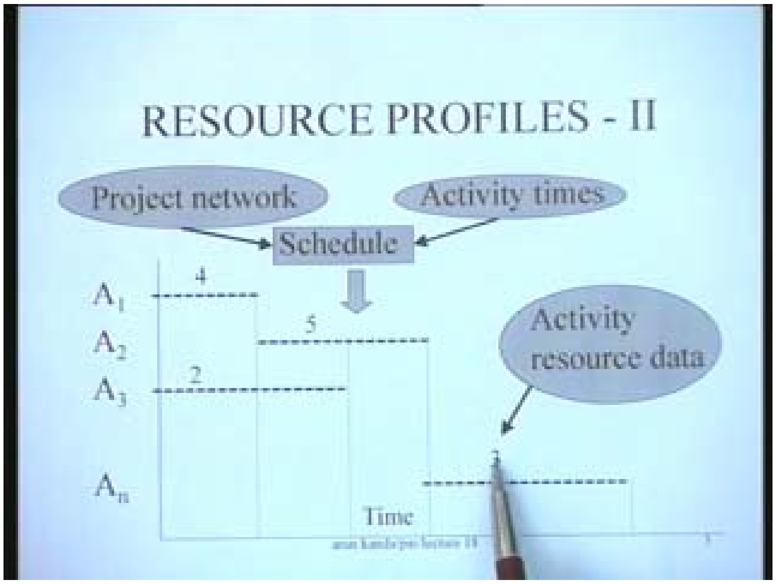

These figures here shown adjacent to each activity are not their durations. The durations are the length of these individual lines themselves but these are the man power needed for accomplishing each of these activities. It may so happen that activity A_1 requires 4 men. Activity A_2 requires 5 men and so on. We have these lists of activity resource data which we now impose on the schedule. If we do this you can see from this particular example that during the period from zero to here 4+2, 6 men are going to be needed. 7 men are going to be needed during this particular interval. Only 5 men are needed in this interval and 3 people are going to be required in the entire interval from here to the project finish. Depending upon which activities are active at what particular point of time we can determine the resource usage profile.

For this particular example, the construction of the resource usage profile shows that we require 6 men in this particular interval and then 7 men here and then 5 men here and then 3 men for the subsequent part of the activity. This particular graph is called a resource usage profile. It shows the variation in the resources which is going to be needed to accomplish the schedule which we had required. What we are trying to say here is that we are going to need 6 people in the beginning till this point in time and then subsequently we are going to need 7 people up to here and then there is a drop and we are going to need only 5 people during this particular period of time and then again there is a drop and so on. This information is vital to the planner, to the project manager because it would help him to identify exactly what is going to be the resource requirement for the particular project and moreover if you are interested in hiring and firing man power from this information you know exactly how much man power is required during what particular periods of time. You make your provisions for hiring and firing appropriately. Similarly if this is a capital equipment like cranes you know when to hire, how many and this particular information again is really very vital when you are trying to talk about the resource profiles.

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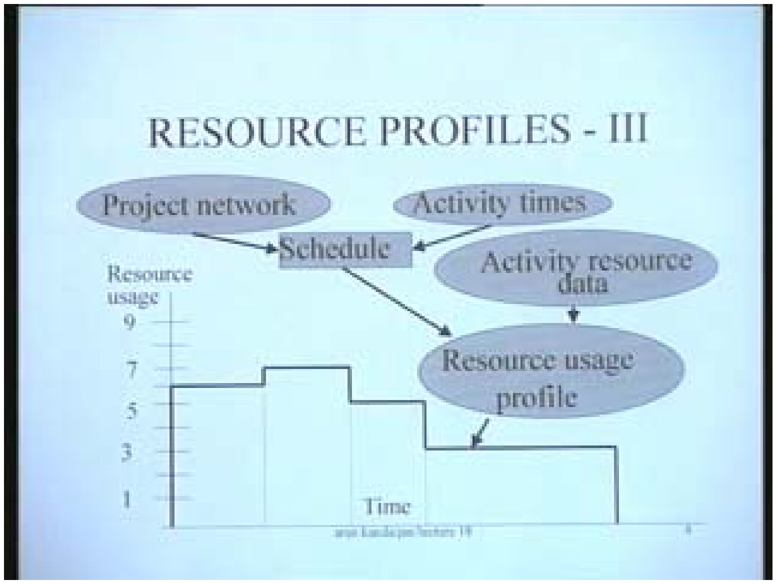

When we are talking about resource considerations in projects which is the theme of this lecture today we are primarily concerned with the construction and the manipulation of these resource usage profiles. Before we go into the various kinds of procedures which are available for dealing with these resource profiles it's worthwhile to make a distinction between renewable and non-renewable resources and based on that we would see how the methods available for dealing with these would vary. For instance let's look at the concept of what we call non-renewable resources first.

Non-renewable resources are those resources which are often referred to as consumable resources as well. If you look at the resource usage profile of a non-renewable resource, in this category we are basically concerned with the total resource consumption which means if we are at time t here what we are interested is in the total consumption that is the area under the curve up to time t. When the project ends at the final project duration the total area would give us in fact the total consumption of the resource. For instance if you talk about money this is the rate of spending and then may be at the end of it you would know what is the total amount of money which has been spent and we are actually interested in minimizing that particular total sum of money.

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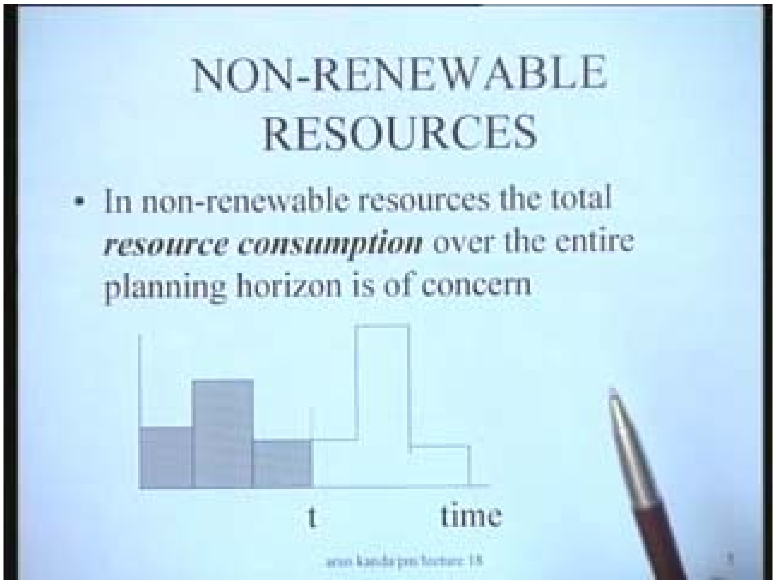

Here our concern is primarily with the total area or the total consumption. Consumption is nothing but the area under the resource usage profile. On the other hand if we look at renewable resources, here the concern is with the total resource usage at each point of time.

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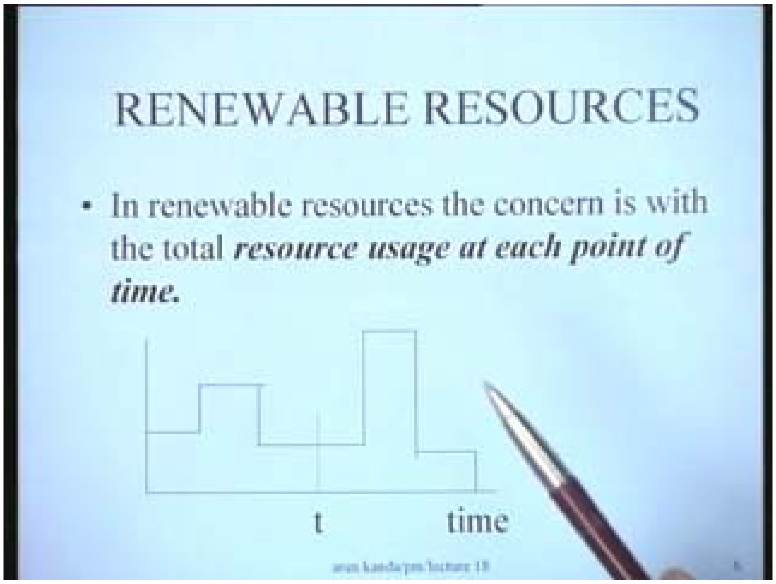

That means we are worried about the total resource usage here, not the total consumption which has taken place here. Resource consumption is the integral of the resource usage. But here for instance we could be concerned with what is the peak or what is the minimum resource consumption or how many dips and how many crests there are in the resource usage profile and things of this nature. If you look at the methods available for handling these different kinds of resources, for the non-renewable resource category typical examples are money. Money is a non-renewable resource. It's non-renewable in the sense that if I have 100 rupee note today and if I spend it, that 100 rupee note is not available to me tomorrow. I have to have a new 100 rupee note. In that sense it's a consumable. On the other hand manpower is a renewable resource. If I have one person working with me today I will use him today. I can use him again tomorrow. In that sense it's a renewable resource. It doesn't get consumed. It all depends upon how you define it. For instance if you define your resources man days, that becomes a consumable resource but availability of man power is a renewable resource in that sense of the term. Looking at examples here money, energy, fuel, raw materials are all instances of non- renewable resources and in fact these resources are best handled by time-cost tradeoffs.

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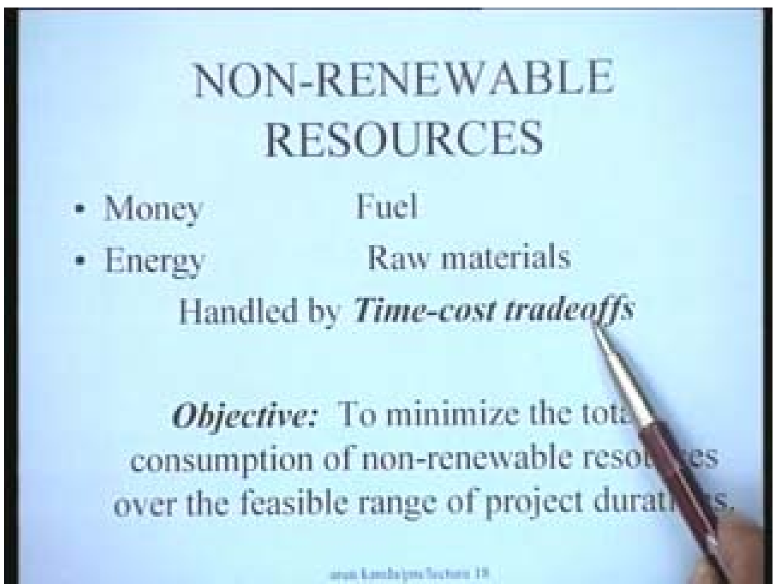

That means the objective here is to minimize the total consumption of non-renewable resources over the feasible range of project durations. That means whenever we are dealing with consumable resources or non-renewable resources those which get consumed like cost we resort to procedures like time-cost tradeoffs which are used for trying to find out the minimum cost schedule or trying to find out the best trade off between the project duration and the project time this kind of thinking and we are already familiar with these procedures.

However when we talk about renewable resources in projects, which is our major concern in this lecture, we are actually talking about resources like manpower or power or machines or fuel flow. All these resources are basically handled through three different mechanisms. The simplest way of handling these resources is through what we call resource aggregation.

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Aggregation, simply means as the name suggests, is the process of working out the resource usage profile from the schedule. Recall the example that we just did. We had the schedule for a project. If you superimpose on that schedule the resource requirements for individual activities then you would have the aggregation of resources and you would be able to work out the resource usage profile. That process is called resource aggregation. Resource aggregation is actually simply trying to find out the resource requirements for a particular schedule. It does not in anyway try to influence those resource requirements. It’s simply like taking a snapshot of a particular schedule. On the other hand resource leveling is more detailed; more detailed in the sense that it looks at the resource profile and you might not find the resource profile very satisfactory. It might want to change the schedule to get a better more acceptable resource profile. Essentially that is the process of resource leveling and limited resource allocation is the process of trying to conform to resource availabilities and trying to minimize the project duration.

Let’s look at these things in a little greater detail. When we talk about resource aggregation as we indicated the objective is to construct the resource usage profiles from the project schedule and the activity resource data. These are the two major inputs that you need for constructing the aggregated resource profile. The result of this would be that you would have the manner in which the resource requirements vary for that particular schedule. This would be a valuable input to the project manager for planning both the procurement and the deployment of his resources.

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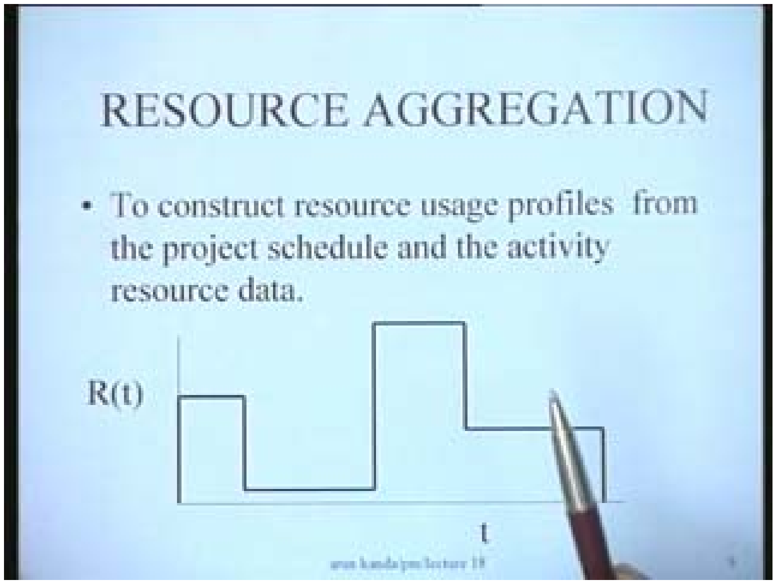

Once we have the aggregated profile suppose that our original profile is the one which is shown here in this dotted line. We might find that this is high during this particular period and we are not really very satisfied with this high. What we might want to do is we might want to smoothen the resource usage profiles. How can we do that? We can do that by shifting slack jobs without worsening the project duration.

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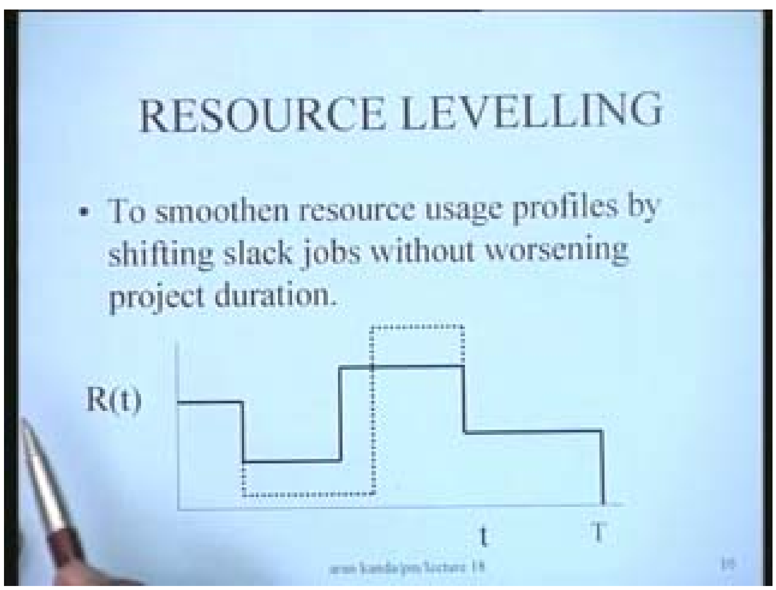

That is the project duration here is fixed and therefore during this particular period when we have the peak we can examine which are the jobs which are currently active from the schedule and those jobs which have slacks those could be shifted either this way or this way and this might mean that some jobs are shifted here. This particular revised profile that we obtain from the original resource usage profile by shifting certain slack jobs is now something like this. It's more level. It has better characteristics than the original profile and this is how we obtain it. Notice that in this process we have not allowed the project duration to increase at all.

There are procedures available for resource leveling. There are both analytical procedures as well as heuristic procedures but the difficulty with the analytical procedures is that they are capable of handling only a small number of jobs or very small projects and for real life projects it's not possible to do resource leveling for a large project which involves hundreds of activities. For this reason generally resort is made to heuristic procedures. Although heuristic procedures do not guarantee optimal solutions nevertheless they are practical procedures which can be used for this particular situation. During the course of today's lecture we will look at two of the heuristic procedures which are commonly used for resource leveling.

Talking about the third problem in resources that is the problem of limited resource allocation or the resource allocation problem as it's commonly called this was our original profile of resources.

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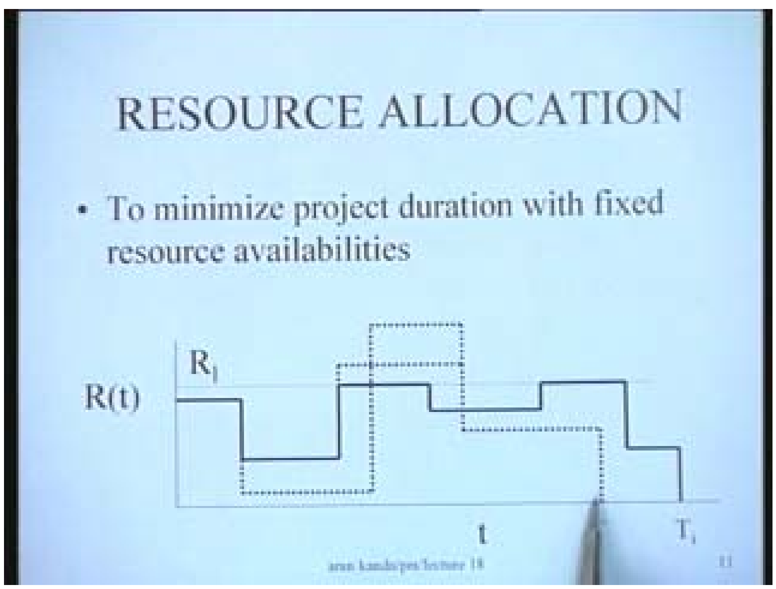

We went through a leveling process and we found that this was the leveled profile, this dotted line here after this which was done in project duration t. But what may happen is that our resource might be limited to R_1 which is this particular line here. Even the best leveled resource which was having a peak somewhere during this period could not be implemented because during this particular period from here to here the resource requirements were exceeding the resource availability. If our resource availability is so much what do we do if you want to implement this particular schedule?

In a situation like this we would have to delay some of activities which are going on during this particular time and once we delay some of those activities in fact some of these activities would be critical activities. Then we might be forced to delay those critical activities which mean that the project duration will tend to increase from T to Ti. That's significant. What we try to do is we try to reschedule jobs. in such a manner that The resource profile is such that all the peak resource requirements are falling within our limited resource availability and in this process we are trying to ensure that the increase in the project duration is in fact a minimum.

When you talk about resource leveling you are holding this duration here, as it were with a plunger, and trying to push it from the top without allowing the plunger to go to the right. That is what resource leveling is all about. But when even the best level resource does not meet your requirements and the resource peaks are higher than the resource availabilities you have no option but to press it hard and allow this to increase slightly. The limited resource allocation problem is to determine that schedule for which the increase in project duration is at minimum. This is the problem in limited resource allocation.

Let us see how these problems can be handled? Look at a small network. This is a small network, a very interesting network because it brings out very dramatically how resource leveling could be done. It's an example that is constructed by Wiest to illustrate the basic notion of resource leveling.

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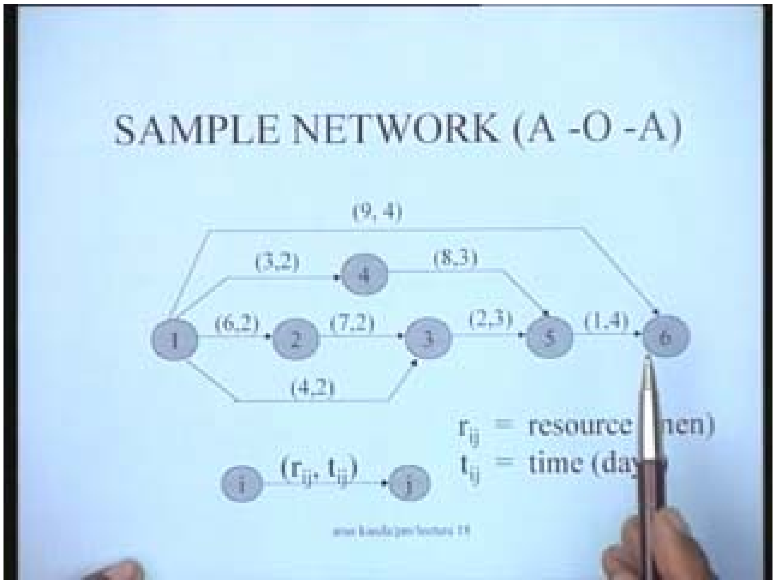

Here are the activities. The first number is the resource requirement and the second number is the number of days required for the job. The resource requirement or the man power requirement and the time required for each job is shown for each of the jobs for this particular network in the A-O-A convention which is shown here. If we take an early start schedule for this network, the early start schedule for this network is shown in this particular graph.

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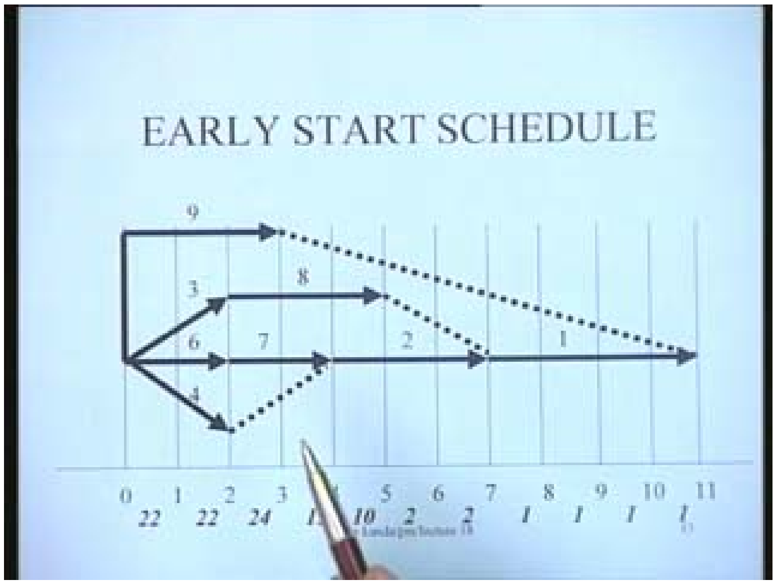

This is a time scaled graph and what we are finding here is that the critical project duration gives 11 days. The critical activities are these 6, 7, 2 and 1. In fact 6, 7, 2 and 1 refer to both the resource requirements and also we can identify the activities by these resource numbers because no two activities have the same resource requirements. If we take the early start schedule then if we sum up period by period that is we do a resource aggregation exercise we find that in this first period job number 4, 6, 3 and 9 are all active. The total resource requirement is 22; 4+6 is 10; 10+3 is 13; 13+9 is 22. Similarly for each period we can find out. In this period the total resource requirement is 22. Similarly in this period the total resource requirement is 24 so that the peak resource requirement of 24 occurs between the second and the third day for the early start schedule and if we were to implement this schedule we would need a total of 24 people to be able to implement this particular early start schedule.

This early start schedule when shown on a typical resource usage graph looks like this. It shows that there is a peak of 22 people during the first few days, then a peak of 24 people and then it drops down and then you have the resource fluctuations. There is only one man needed from the day 7 to 11 as far as this particular project is concerned. It’s a highly imbalanced kind of a profile.

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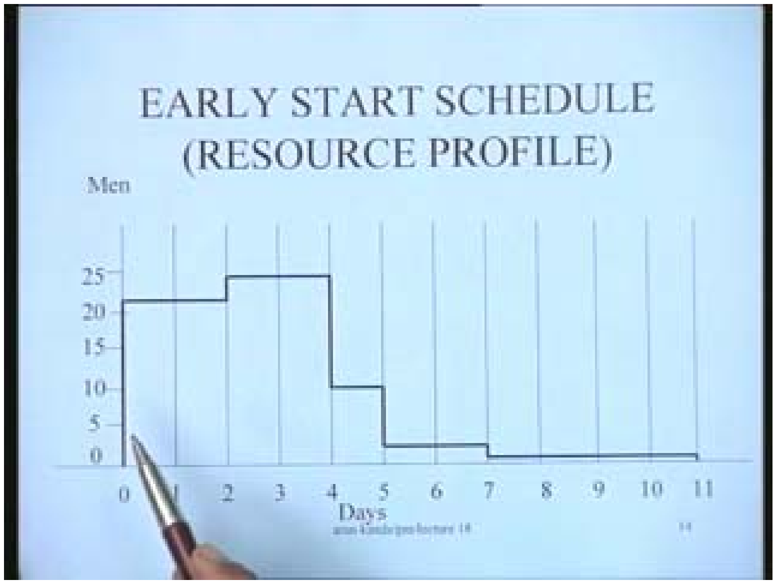

Otherwise also in an early start schedule you expect that most of the resources are going to be consumed early and during the later half you are not using many of the resources. This is what is typical. For this particular example if we look at the best leveled schedule notice the critical path remains the same.

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The activities here are 6, 7, 2 and 1. The best leveled schedule will have to be worked out by some heuristic or by some procedure but in this case you see that the activity 9 which was earlier being done at the earliest is now being shifted to the latest position. This activity continues to be done at the earliest position whereas these two activities 3 and 8 have been shifted so that they are done at their latest position. It's some combination and the consequence is that the number of men required for each day is 10, 10, 10, 10, 10, 10 throughout. In any practical resource leveling exercise you may not be as fortunate as this because this as I told you is a specially constructed example by Wiest which shows this. The best level resource profile in this case corresponding to this schedule is a perfectly leveled resource profile and 10 men are required throughout the time duration of 11 days for this particular project.

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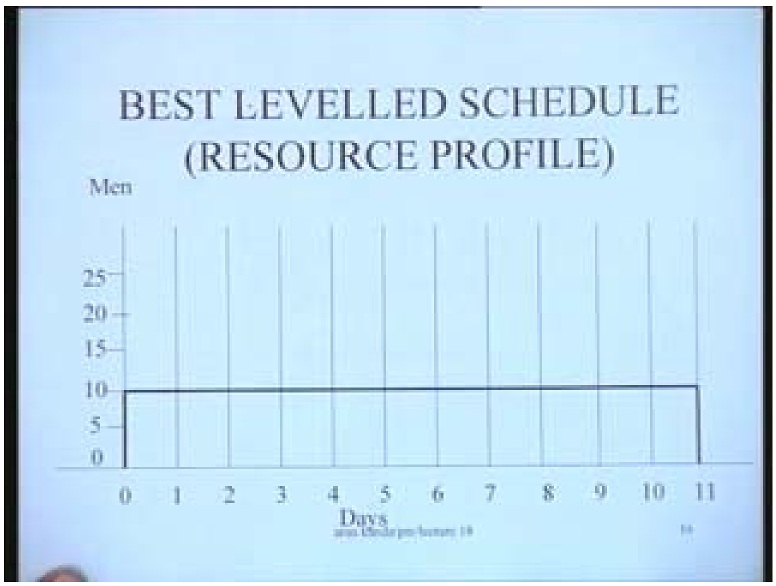

This essentially is the concept of resource leveling whereas corresponding to the early start schedule we were requiring a total of 24 men to implement the job. Here the same duration can be achieved with only 10 men if we have properly leveled our resource requirements and it's a much better schedule because all these people are being utilized uniformly throughout the project. But if you follow the other case you would have lots of costs of hiring and firing people and you might even have difficulties in trying to recruit man power for doing that kind of job. Especially if the resources that you are talking about are skilled resources like skilled engineering man power or skilled managerial man power then their availability is limited and it becomes very difficult to find or implement a schedule which has a lot of fluctuation in the resource profile. From this example today we will look at some procedures for resource leveling and defer the discussion on resource allocation to next lecture.

Let's look at some of the major criteria which are involved in the resource leveling process. Let's look at the criteria in leveling. Different authors have suggested different criteria to be used for resource leveling. One of the most commonly used criteria is the peak level of the resource usage. The peak level of the resource usage means you look at the resource usage profile and wherever is the maximum resource usage you try to minimize that and that's the objective they say. In fact there is a trigger level setting heuristic of Wiest which we will discuss shortly that tries to look at this particular criterion and bases it's entire computation with the objective of minimizing the peak. However what is the major defect with this criterion of the peak?

The major defect is that when you have the entire resource profile you are looking at only the worst part of it, one particular area where it is worst and rather than trying to develop an objective function for the entire resource profile, what can happen is, there might be just one resource, one peak and the other resource profile might be acceptable to us. For the sake of one peak it might not be worthwhile to penalize that particular resource profile unnecessarily. It has been suggested that may be a criterion like sum of the squares of the resource usages could be a very good criterion to find out how good the resource profile is because for all schedules the total area under the resource usage curve is a constant. When work is scheduled the total work done has to be the same. But if there are imbalances it's those imbalances that we are trying to talk about and the sum of the squares of the resource usages if we try to minimize this, this would be a good idea.

To give you some intuitive concept of this particular resource suppose that we have a resource usage for 2 days which is of the order of 4 men are consumed on the first day and 4 are consumed on the next day. This is the best possible thing which can happen. It's perfectly balanced. Let's try to increase the amount of imbalance in this. What can happen is 3 men here, 5 men here, 2 men here, 6 men here, 1 man here, 7 men here and in the worst case you have 0 men here and 8 men here. It could be distributed either this way or that way, doesn't really matter. If you look at the sum of the squares in this case you will have 16+16. Here you will have 9+25. Here you will have 4+36. Here you will have 1+49. Here you will have 0+64. The sum of squares is minimum and is equal to 32 when this is best balanced which is 4, 4 and it's equal to 64 when it's the worst situation when there is no man operating here and all the 8 people are here and in between you find that from 64 to 50 to 40, 40 here, 50 here, 34 here, there is a progressive decrease. This is the intuitive concept behind using the sum of the squares as a criterion to measure the effectiveness.

If you have a large resource usage profile, you have a profile which reads something like this. You have all kinds of fluctuations in this. What you can do is you can find out the resource usage of the first day and square, on the second day and square and so on if this runs up to n capital days to this. This entire thing would give us a measure of the degree of balance of this particular profile.

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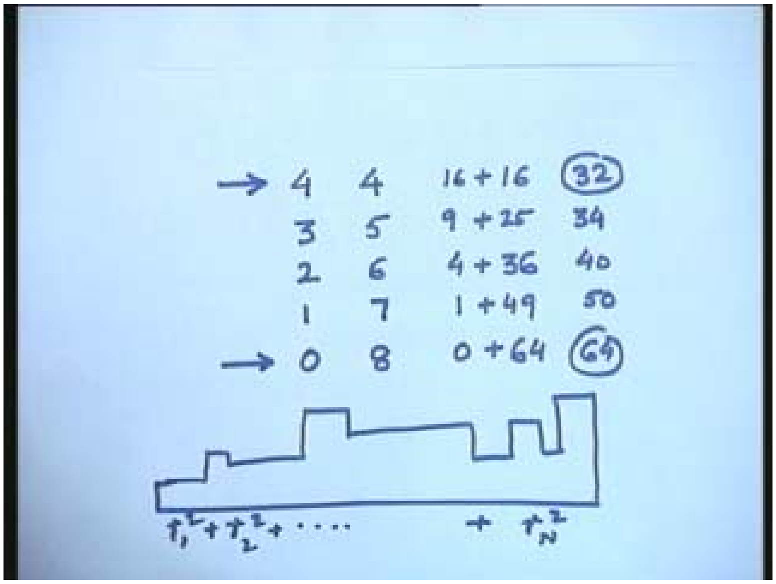

Incidentally this is the criterion which has been used by Burgess and Killebrew in using their particular algorithm. Let's see the logic of the work load smoothing heuristic due to Levy, Thompson and Wiest which was proposed very early and which has been patronized by Wiest. The basic procedure can be described very simply. You start from an early start schedule as we did earlier and when you start from an early start schedule, corresponding to this schedule you can work out the resource usage profile just as we did. Once you have worked out the resource usage profile you can know where the peak resource level is and this particular heuristic identifies that peak and it starts to set a trigger level. That's what it does. It sets a trigger level 1 unit below the peak. That's what it does. This is the basic idea in the whole procedure.

You can say that a trigger level is actually a kind of a target. You are trying to reduce the peak of the resource usage profile by 1 unit at a time and since you already have a peak which is a certain value, your target is now 1 unit below the peak and then what you do is you examine the jobs which are currently going on during the peak period and what you try to do is you try to shift those jobs to find a schedule that satisfies the trigger level. If you find that there are a number of jobs who have enough floats so that they can be shifted beyond the peak then those jobs could become candidates for shifting and you could reduce the duration of the peak hopefully. This is the general logic. You are shifting jobs to find a schedule that satisfies the trigger level. If this is not possible, if there's no schedule possible which satisfies this new trigger level you would stop. That means the one particular schedule that you have is already the best schedule. Otherwise you continue and continue means you found a better one here. So you set your new trigger level 1 unit below and continue the process in this particular manner.

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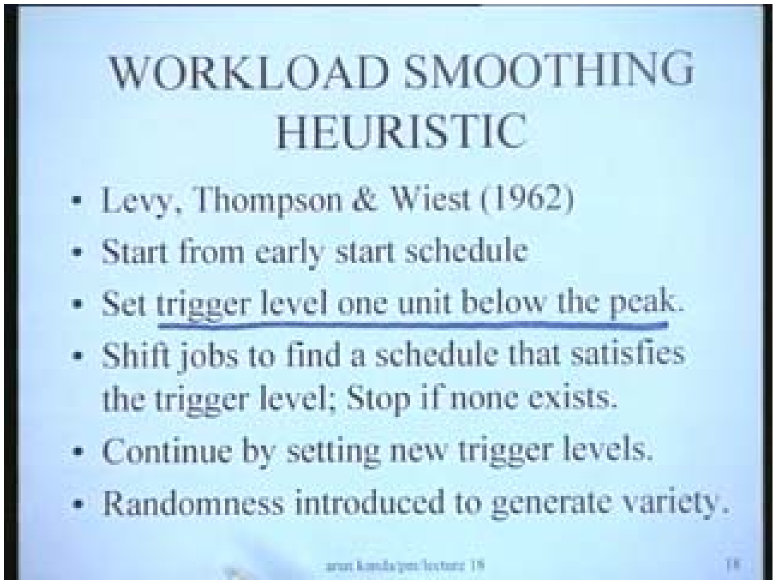

One feature which has been introduced into this particular heuristic is the element of randomness. Randomness essentially means that you have to examine jobs which are going on during that particular peak period. Suppose there are k jobs going on. You call them A1, A2 and so on up to Ak. You have the option of shifting any one job or a combination of jobs so that the peak is reduced. Which job you pick up can be done by a random process out of the available candidates. The advantage of randomness would be that when you run the program the next time you can have a different solution. If you run it may be 20 times you will have 20 solutions and you can pick up the one which is the best. That is the basic advantage of this particular heuristic.

Let us now look at the other heuristic. That's right. It can happen. Because of this element of randomness what can happen is that the first time you run the program you are able to reduce the peak from may be 20 to 18. The second time you run the program you might be able to reduce it from 20 to 17, more or even less as the case may be because there is no guarantee of optimality in the entire procedure. What we are simply doing is examining the jobs which are going on during the peak period and making a list of those jobs which could be shifted and in making that list we are making sure of two things. Those jobs which have enough slack available with them so that they can be shifted beyond the peak. Those are the jobs which should really be shifted. That is not necessarily true that shifting those jobs will necessarily give you a schedule because what can happen is shifting one job from here to there could create a new peak somewhere else and the advantage of the trigger level is that we don't want to exceed the trigger level at that particular point. All schedules which give you peaks above the trigger level are actually ignored and only if you find a solution which gets you a schedule below the trigger level, you store that solution. That's the basic idea. This is a heuristic in which the objective function is to minimize the resource peak.

The second heuristic that I will briefly discuss with you is the Burgess and Killebrew heuristic which is actually an 8 step procedure designed to minimize the total sum of squares of the resource usage. The objective function is to minimize the total sum of squares of the resource usage and I already gave you an intuitive understanding of this particular objective.

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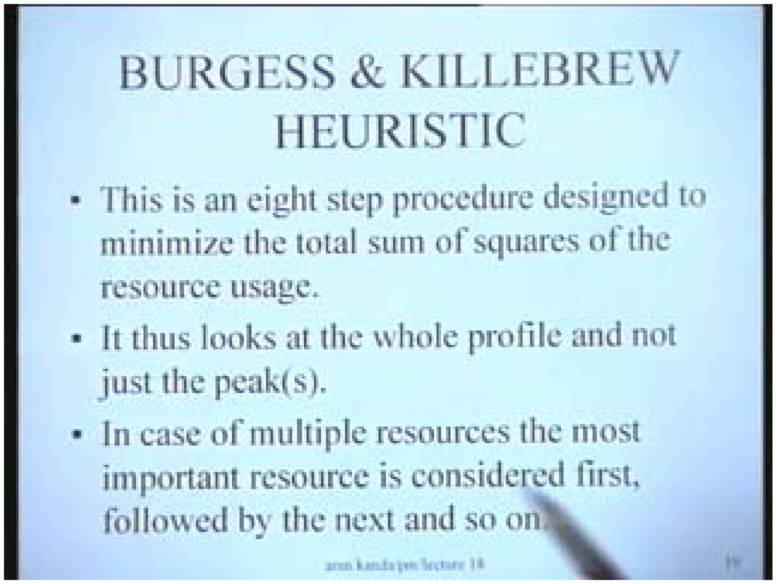

It thus looks at the whole profile and not just the peaks this particular procedure and in case of multiple resources the most important resource is considered first followed by the next and so on. For instance you have two resources like skilled man power and cranes. If you think skilled man power is more important then apply the heuristic with first peak skilled man power and then keeping that as constant try to work up the cranes. I will briefly go thorough the steps of this particular procedure so that you have an idea. The starting step or the initialization step simply looks at listing project activities in order of precedence. In fact any topological ordering of the activities of a network will give you the activities in order of precedence and therefore this ordering is not unique.

In order to pick up a specific ordering what these people have done in this particular heuristic is that they say that you arrange the activities in order of precedence by arranging the arrow head numbers in ascending order. Each activity will have i j; j is the arrow head number. You arrange the activities in arrow head number and when two or more activities have the same head number that means when there are a number of activities culminating into the same node then list them so that the arrow tail numbers are also in ascending order. Basically by following this numbering scheme you have in fact a unique listing of the jobs for a given node numbering scheme. If you change the node numbering scheme you will have a different order. Then you add to this list the following information: the duration of the job, the early start and the slack values, what is the total float for each activity? That’s the information that you would require.

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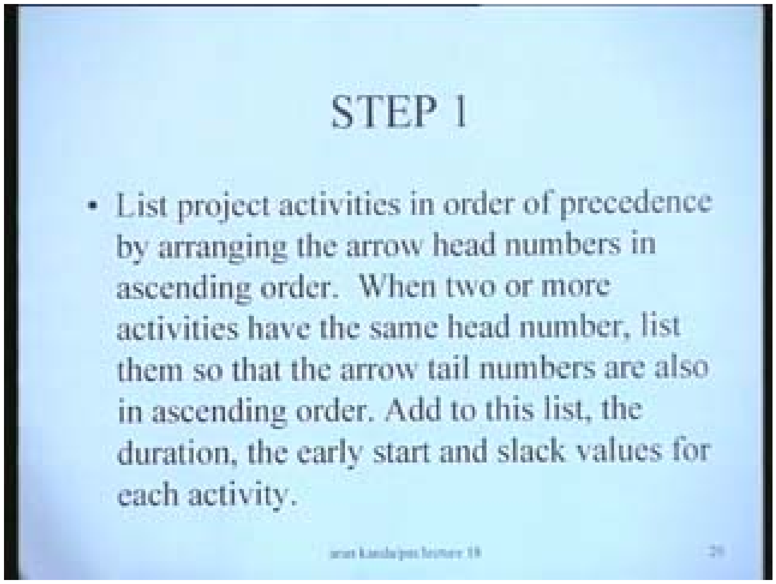

What is then done is you have a list of the activities in the order of precedence. In this list you start from the bottom. What it says is look up the last job first starting with the last activity, the one at the bottom of the diagram, schedule it to give the lowest total sum of squares of resource requirements for each unit. Look up the last activity. The last activity can be slided this way or that way depending upon its float. We pick up the position for that activity, in that slot where the total sum of squares of the resource requirement is minimized and then we fix that activity there. Another important thing is if more than one schedule gives the same total sum of squares then schedule the activity as late as possible to get as much slack as possible in all preceding activities. That’s the logic.

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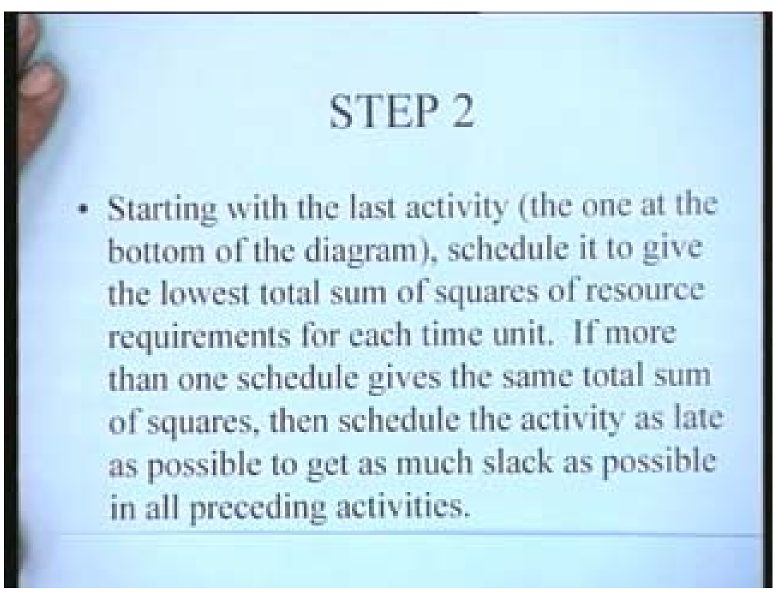

It's just a process of shifting each activity. When we shift the activity we can keep it either at the earliest value or we can shift it by 1 day or we can shift it by 2 days or utmost we can shift it by the amount of total float for that activity. You compute for each of these what is the total sum of squares of the resource usage and wherever it is minimum, freeze the activity there and if there are possibilities that either here or a later value gives you the same sum of squares keep that activity as late as possible so that the earlier activities can then have more of float.

Step 3 then says that the last activity which we have just considered keep it fixed and repeat the earlier step, step 2 on the next to the last activity in the network taking advantage of any slack that may have been made available to it by the rescheduling in step 2.

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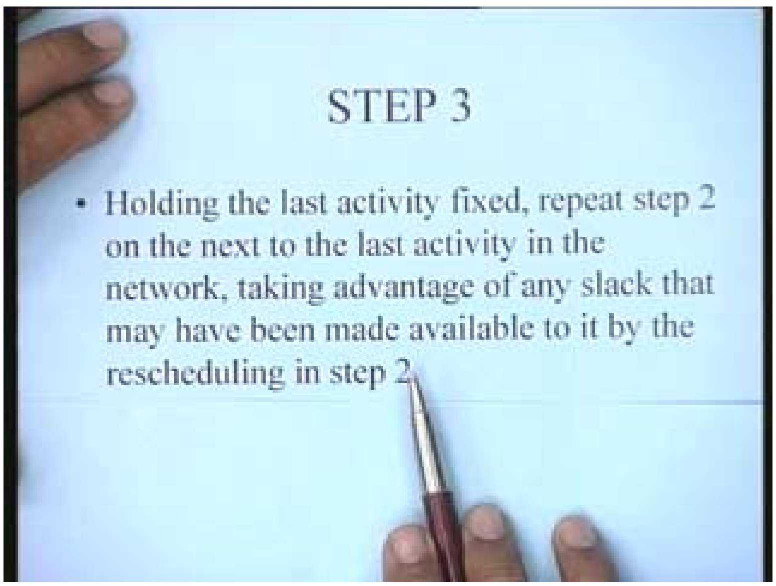

Once you have taken the previous activity and fixed it the other activity can now be slided up to that point. Find out now for the next activity as to where it can go and again try to fix it so that the sum of the square is minimized for that particular activity. That's the basic logic and we continue this step. Step 4 of the algorithm says that continue step 3 until the first activity in the list has been considered. This completes the first rescheduling cycle. This is basically one complete iteration of the algorithm.

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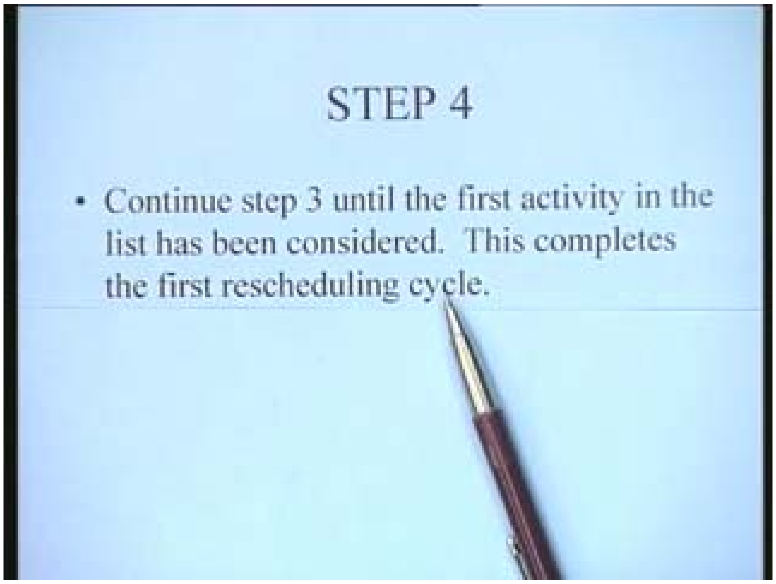

You start with the early start schedule. You have a Gantt chart of the activities. Start from the lower most activity. Shift it depending upon its float and freeze it where the total sum of squares is minimum. Then take the next one and again do the same thing and the next one do the same thing and the next one do the same thing till you come to the top of the list which is the first activity and then this completes one rescheduling cycle. Each time you shift an activity the sum of the squares of the resource usage will change because each activity is consuming some resource. Shifting it would mean that its position changes. The resource usage and resource requirements will keep on changing. Not only this. In fact with additional rescheduling cycles also the sum of the squares could change. Why because we are taking one activity at a time. We have fixed up this activity and then we change this activity. It is quite likely that when we do this again there could be a further change in sum of squares because of the changes that have now been made globally. We are handling one activity at a time for ease of manipulation. We take up each activity and we shift the activity as a block. The activity is shifted depending upon its total float by 1 day or 2 days or 3 days. What you are probably referring is the process of splitting the activity. If there is a possibility of splitting the activity then you can use the same algorithm. What you can do is the original activity can now be modeled as two activities in series and each one of them can now retain their structure. Then they would have the flexibility of being split. This is possible using the same algorithm.

The next step in this particular algorithm would be to carry out additional rescheduling cycles. That means from normally most of the changes take place in the first rescheduling cycle. In the second rescheduling cycle very few changes take place and in the third rescheduling cycle there are no changes. This is the normal thing. Carry out additional rescheduling cycles by repeating steps 2 through 4 until no further reduction in the total sum of squares of the resource requirements is possible noting that only movement of an activity to the right that is scheduled later is permissible under this scheme.

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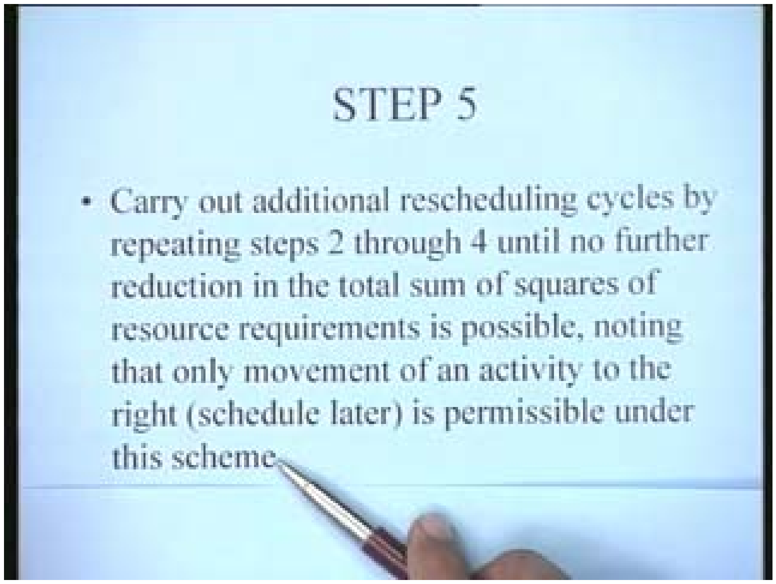

Since we have started with an early start schedule you are only investigating the possibility of shifting the activities to the right and not back to the left. It's a one directional search and you might have shifted it by 2 days. The total float is 4 days. In the subsequent rescheduling cycle you will again investigate the possibility of shifting the activity only by 2 additional days and not by the whole amount. The subsequent rescheduling cycles would in fact reduce the amount of shift that is possible for each activity. You continue this till there is no further reduction in the sum of squares of the whole activity. You know the first rescheduling cycle. You calculate the sum of the squares at the second rescheduling cycle. If it's lower then you go for the next one. If you find it the same as the previous one then you will stop. If this resource is particularly critical then repeat the whole process on a different ordering of the activities which must list the activities in order of precedence.

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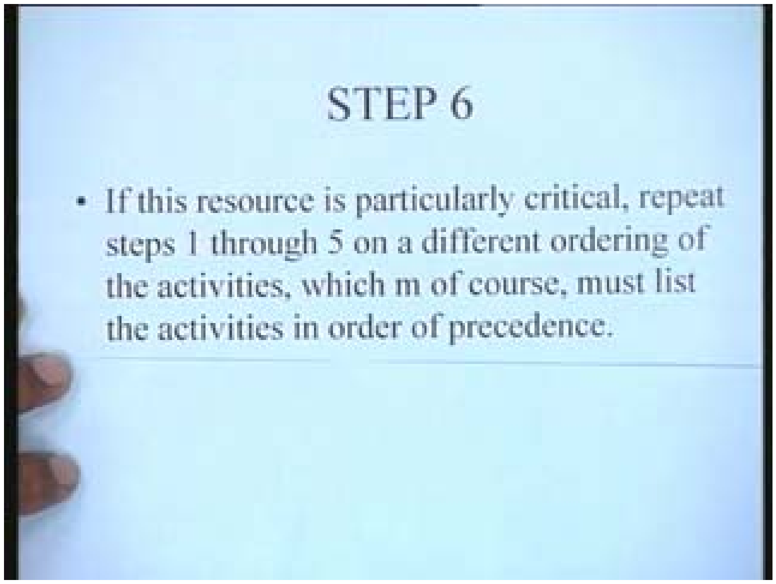

We started off with one particular precedence order. There are many topological orderings. You can start with some other topological ordering and do the same thing and since it's a heuristic procedure you might get a better solution. That's the only thing. It says if this resource is critical then you might as well do it for a couple of different topological orderings. The starting procedure would be the same. The last activity you would take and go through this from the last to the first but the sequence of placement of activities is topological order. So the last activity might not be the last one. It might be last but one of the activity. If there are 3 last activities in a project which have no successors then there could be 3 different sequences. So that possibility can arise. Step 7 of this particular procedure specifies that choose the best schedule of those obtained in steps 5 and 6.

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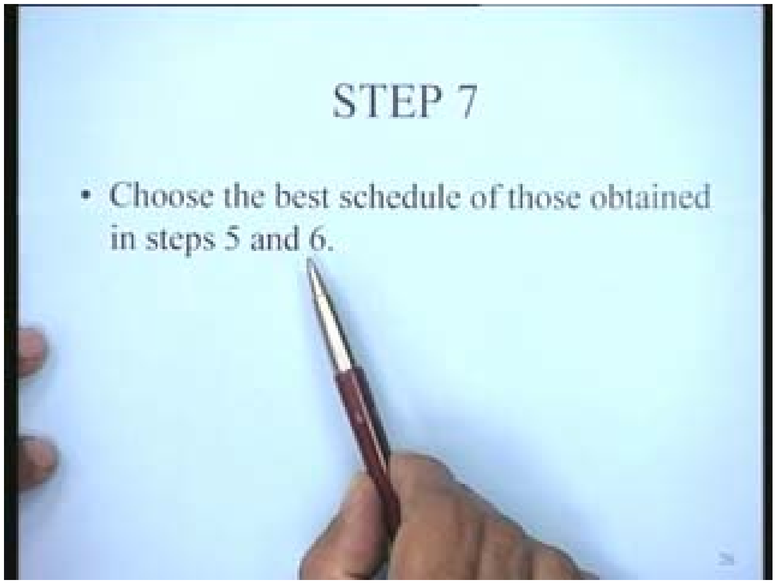

The final step says that having obtained a schedule you can make some minor adjustments to it manually. Make final adjustments to the schedule chosen in step 7 taking into account factors not considered in the basic scheduling procedure.

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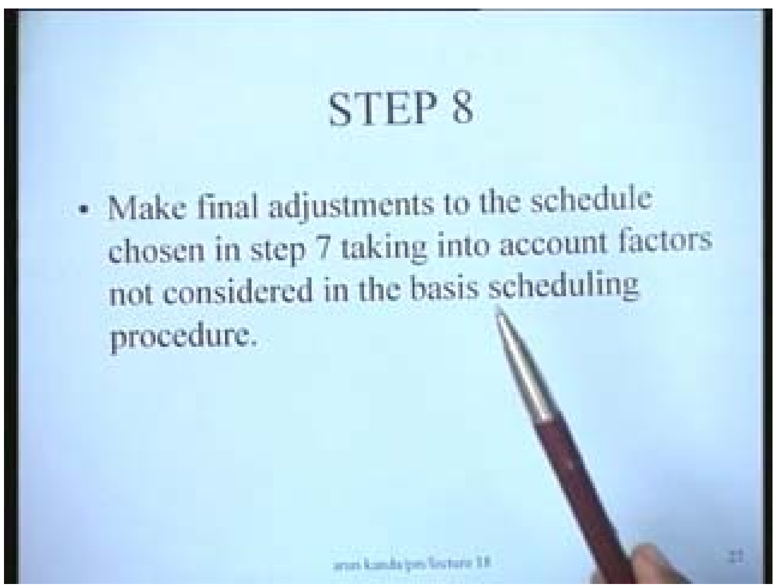

That means if there are any practical constraints which you want to incorporate, those could be incorporated in the schedule and manually modify it before you take it. Just to give you an example of how this particular schedule works here is a small network which has 9 nodes as shown here. Nodes are numbered from 0, 1, 2, 3, 4, 5, 6, 7 and 8 as shown here.

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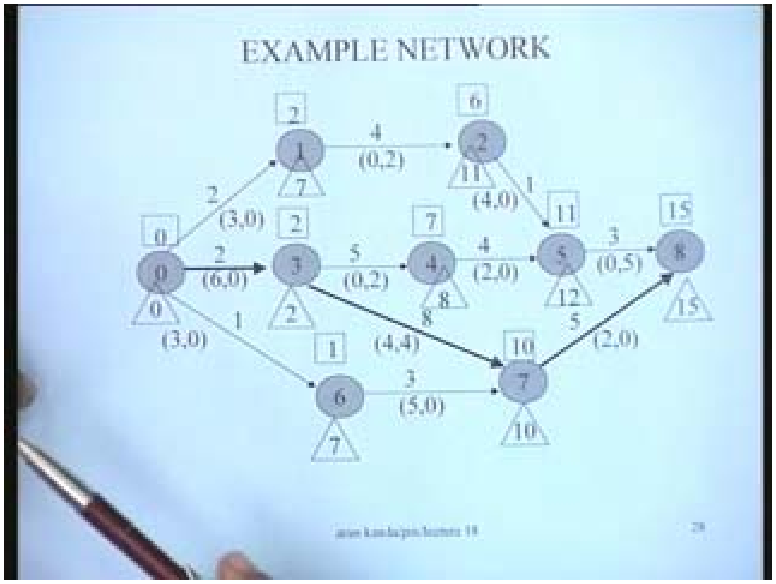

The number here shows you the duration of the activity and these two numbers show you that there are two resources. This one is man power and this one is the number of cranes, number of material handling equipment needed for this particular activity. Some activities require no men here but some cranes. Some require 3 skilled men and no cranes. So this is man power. There could be some activities which require both. So we are talking of two types of resources. If you carry out a forward pass in this particular network with these time durations you get these earliest occurrence times. If you carry out a backward pass you have these times which are shown in these triangles here. These are the latest occurrence times for the nodes and you can easily see that this is a critical path for this particular network. That means it has duration of 15 days and these are the resource requirements for this particular activity.

For this particular network the Burgess Killebrew procedure which we just applied was applied and I will show you the final results in terms of what was observed. Before and after we started with an initial early start schedule, the initial resource profile for resource A was something like this. This is for 15 days like this. These are the resource requirements for 15 days. The peak was occurring on the second day and the peak was 14 whereas the final resource A profile after this procedure was something like this so that the peak now was only 9 days and it was occurring on these 3 days here. There was a substantial reduction in both the peak and the total sum of squares. Similarly for the resource B, the initial resource B profile was something like this for that network. The resource peak was 8 days occurring on these 4 days.

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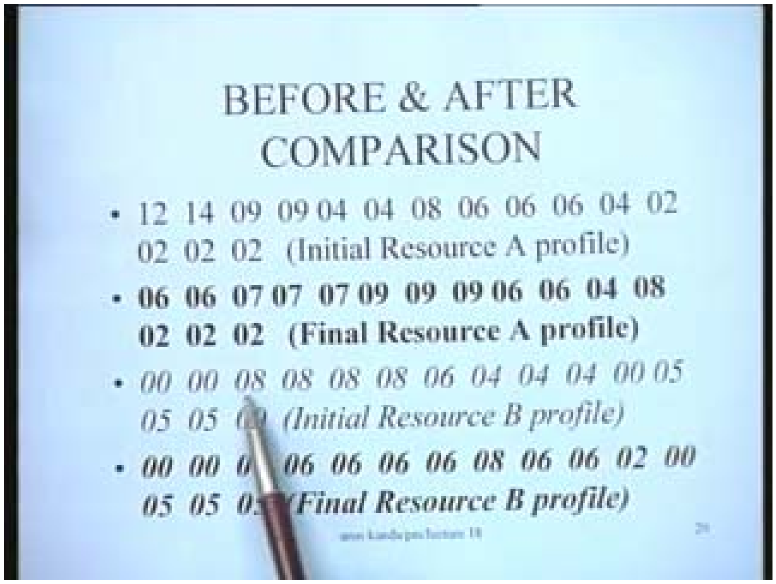

After the solution was applied the peak resource day was still 8 but the duration had gone down from 4 days to just 1 particular day and this was the consumption of resources as far as final resource B is concerned. You do it for both but you take it for resource A. First you use it for resource A because resource A was important and after having done that you can do it for resource B. You will not make those changes which result in worsening of the resource profile of A. In this particular example the initial sum of squares for resource A was 738.

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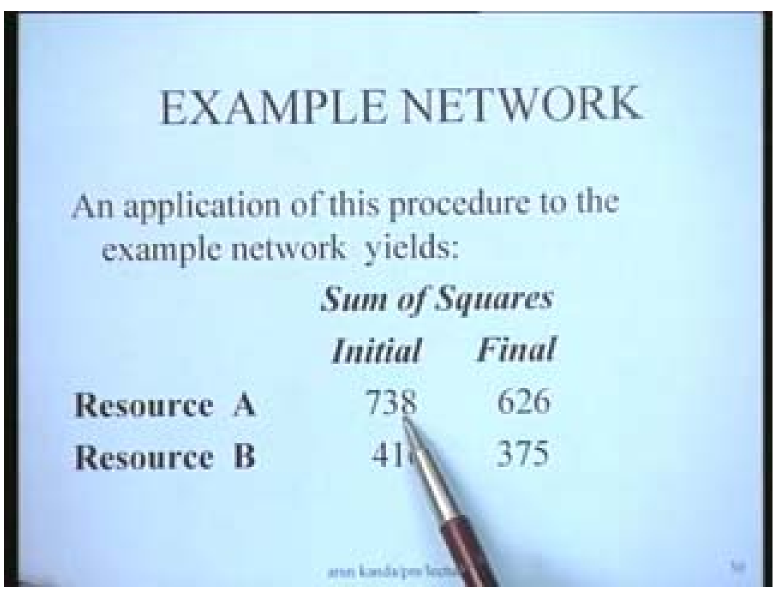

It was brought down to 626 and for resource B it was brought down from 416 to 375. This was the final result for this particular problem. This gives you an idea of how these two heuristics, namely the trigger level setting heuristic of Wiest which is primarily aimed at bringing down the peak and Burgess and Killebrew heuristic which is looking at the entire resource usage profile can be used in practice.

In order to summarize what we have tried to do today we have discussed the notion of renewable and non-renewable resources essentially in this particular lecture. We have seen the time-cost tradeoffs are a legitimate means to handle non-renewable resources like cost.

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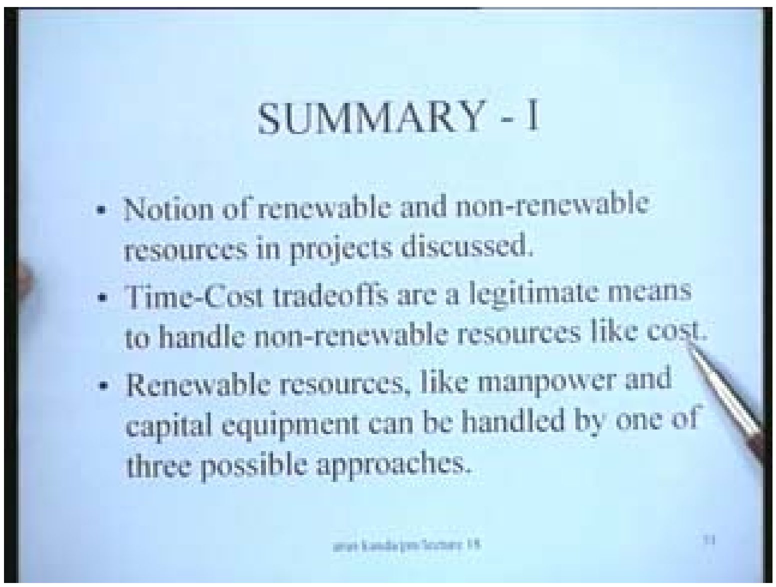

Renewable resources like manpower and capital equipment can be handled by one of three possible approaches which we have seen. These three approaches are the approach of resource aggregation which is nearly taking a snapshot and trying to find out what are the requirements of manpower for a given schedule. Then if you are not satisfied with that profile you can resort to leveling and bring down the hiring and firing costs and have a more balanced leveled profile and the third technique for dealing with these renewable resources is limited resource allocation.

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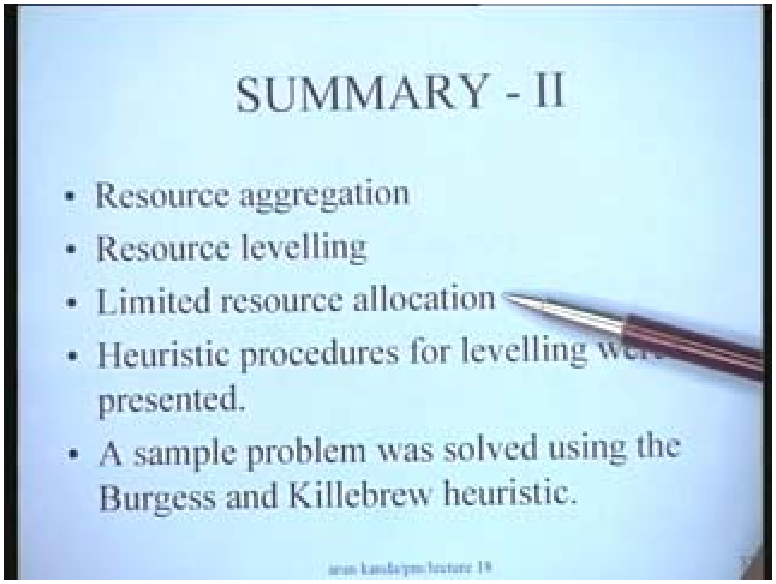

Heuristic procedures for leveling were presented. We looked at two such procedures and a sample problem was solved using the Burgess and Killebrew heuristic. Thank you!