Construction Methods and Equipment Management
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Lecture - 1
Planning Process of Equipment

Hello everyone, I welcome you all to this lecture 1 of the course construction methods and equipment management, see the topic of lecture 1 is planning process of equipment.

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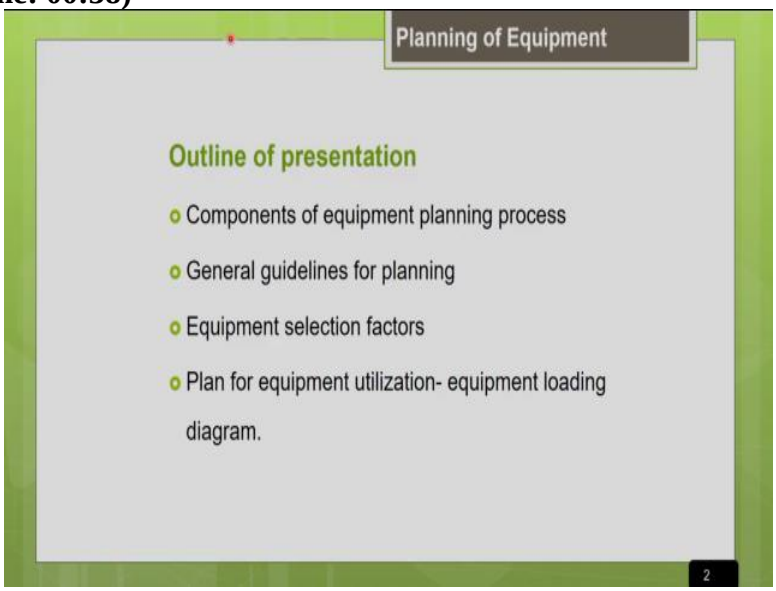

So, this is the outline of the today's presentation, I will just introduce the components of the equipment planning process firstly, followed by a discussion on general guidelines for planning then I will provide you in depth view of various important equipment selection factors, then we will conclude with the how to plan for the equipment utilization with the help of equipment loading diagram.

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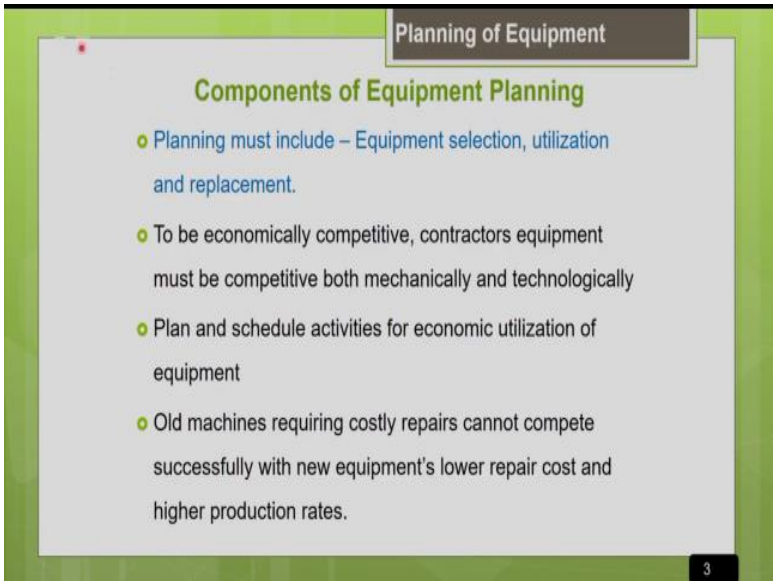

Planning as everyone knows, planning is a very critical task for any construction project implementation. On a similar note, planning of equipment is also very critical because huge amount of investment is involved in the equipment the selection of the equipment is only going to affect your construction methodology of the project, project completion time as well as the cost of the project. Hence, the selection of equipment is very critical for any project. So, now, let us see what are all the components of equipment planning process?

So, the planning must include your equipment selection, then we have to plan for the equipment utilization, then finally, we have to plan for the replacement of the old machine with the new machine basically, as I told you in the introduction lecture, now, we have achieved a lot of advancement in the equipment technology, there are so, many machines available even for the same job.

Now, it is really a tough task for the equipment planner to choose the right machine for the right job. So, generally how do they choose it? So, there are some guidelines generally they go for economical method of approach. So, basically they compare the machine performance in terms of productivity. Whichever machine gives you the maximum productivity at the lowest possible cost then they will go for the selection of that particular machine.

So, this general guideline we should always keep in mind. To be economically competitive in the construction market, the contractor's equipment must be competitive both mechanically as well as technologically. So, not only the equipment meet the functional requirement, it is not sufficient, it should also be technologically competitive in the market. Because there are so,

many competitive models available in the market, which are more technologically competitive which can give you a better productivity and lower costs.

So, our equipment should be competitive both mechanically as well as technologically in the sense it should also give you a very high productivity at the lowest possible cost. Then we have to plan and schedule the activities for the economic utilization of equipment. So, we have invested huge amount of money in the equipment. So, the equipment should work productively, and it should be able to generate profit for us.

So, plan and schedule the activities so, that we can have economic utilization of the equipment in the project with lesser idle time. And another important thing to be noted is we should not just cling on to the old machines, which are either worn out due to wear and tear or the productivity may be lesser with increase in age of the machine we know that the maintenance and repair costs of the machine will increase.

So, when there are so many competitive models available in the market, we should look for the optimum replacement time of the old machine with a new machine because a new machine can give you a better productivity than your old machine and its maintenance and repair costs will be lesser than your old machine. So, there are different replacement analysis guidelines, we should follow that and look for the optimum replacement time of the old machine with the new machine.

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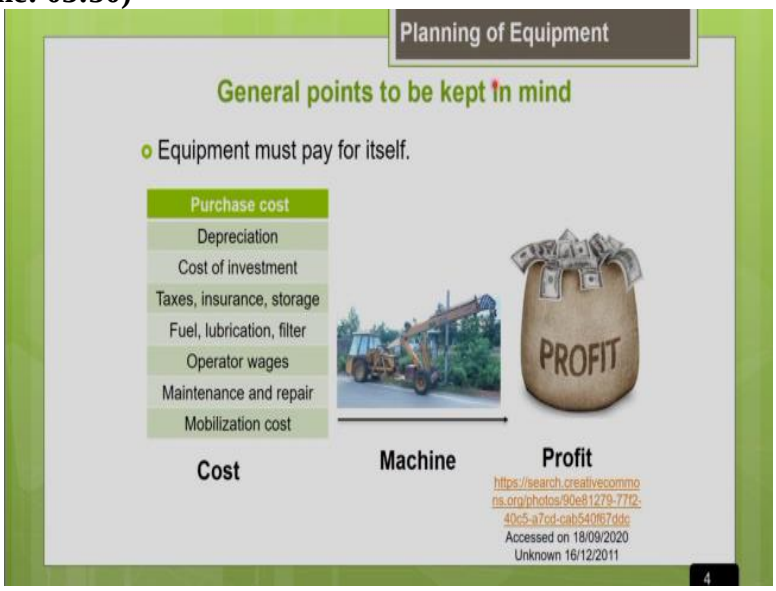

So, before discussing about the list of the important equipment selection factors, let us have a general discussion on the general points to be kept in mind when planning for the equipment. The first point is equipment must pay for itself. So what I mean by that is generally we have invested a huge amount of money in the equipment, there are a lot of costs invested in the equipment.

So everyone knows about the purchase cost associated with the machine other than that there are components of ownership cost also like your depreciation cost, cost of investment, say for example, if you are going to procure the equipment through a loan, you may be paying interest for the loan that is the cost of investment. Similarly, your equipment is an asset so you have to pay the property taxes for the equipment so that is a part of ownership costs.

Similarly, you have to pay the insurance premium to protect the owner of the equipment from the loss of theft or fire or due to accident. So the insurance premium whatever we pay, it forms a part of your ownership cost, then the storage cost of equipment, then the other operating costs, like your fuel costs, lubricating oil costs, filter cost and the wages to pay for the operator, maintenance and the repair cost and the cost of mobilization of the equipment to the project site all these costs make up the cost of the equipment.

So, you should understand that there are a lot of costs involved in the machine. So, how to estimate all these costs we are going to discuss in the upcoming lectures. So, there are many lecture hours dedicated, how to estimate the costs associated with the machine there I will give you in depth information on the estimation part. So, as of now, what we need to know is since lot of cost is invested in the machine.

The equipment must be engaged productively in the construction project site and you should be able to generate profit out of that. The equipment must be able to recover all the costs invested in the particular project and it should be able to generate the profit.

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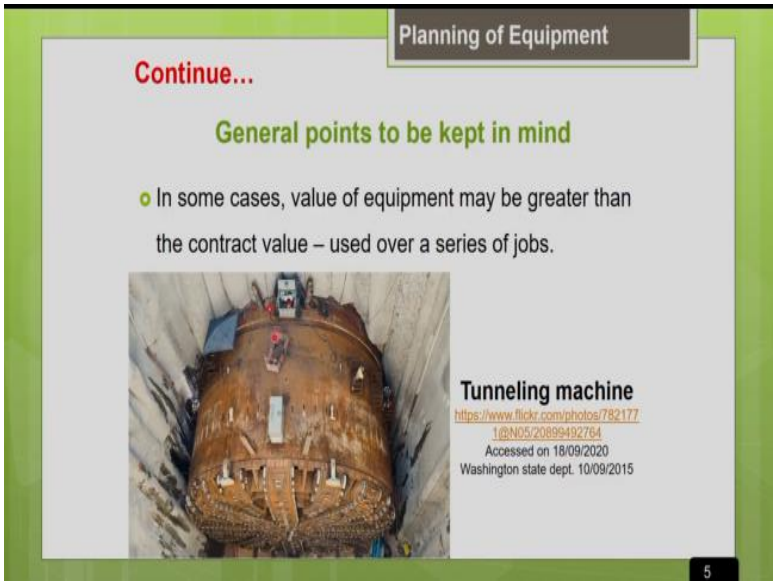

Another point to be kept in mind is in some cases the value of the equipment may be greater than the contract value that means, there are some high end equipments like say tunnel boring machine it may cost so many hundreds or crores. Similarly, cranes of heavy lifting capacity like 2000 tons lifting capacity crane. So, they are all high end machines in this particular case, there are chances that value of equipment may be greater than the contract value.

So, in this particular case, it may not be possible for you to recover all the costs invested in the machine in one particular project itself. So, you may need so many series of jobs to recover the cost invested in the machine. So, when you plan for procurement of such high end machines, we should do proper economic analysis, whether there is a likelihood of future jobs which may involve the utility of the particular machine. And you have to work out the economics before purchasing such high end machines.

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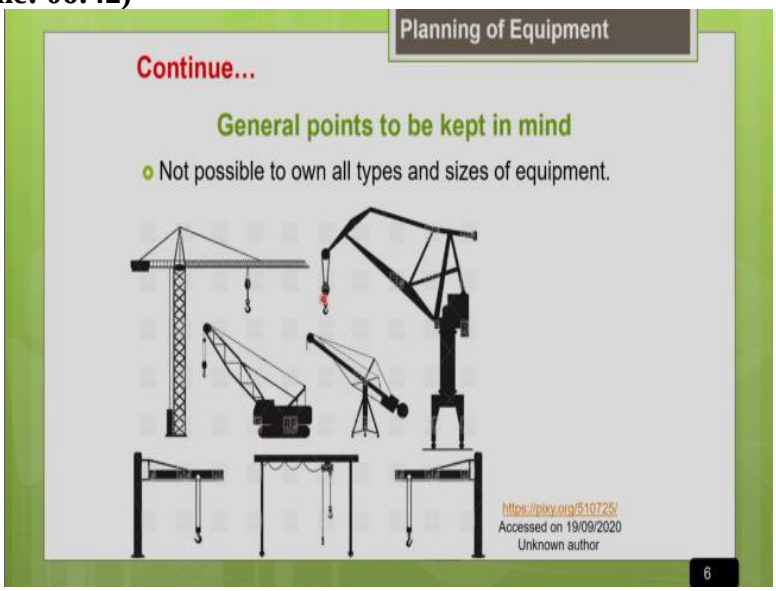

And another general point to be kept in mind is, it is not everyone then it is not possible for a contractor to own all the types and all the sizes of equipment. Say for example, if we take an excavator, there are different bucket capacities of excavator, so, it is not possible for the contractor to have all the bucket capacities models in the project site. Similarly, if you look into the crane, there are different models of crane with different lifting capacity.

So, you can have a horizontal boom crane, you can have a luffing jib crane, you can change the angle of boom that is called as luffing jib crane or you can have a telescopic boom crane. So, different configurations are available with different capacities. So, it is not possible generally to own all the types, but the contractor will generally make a decision whichever equipment is more frequently used for his job.

And based on his experience he can anticipate in his future series of jobs, which is likely to be most frequently those equipments he will purchase the other equipments which are not frequently used, he will generally decide to rent that will be the best decision.

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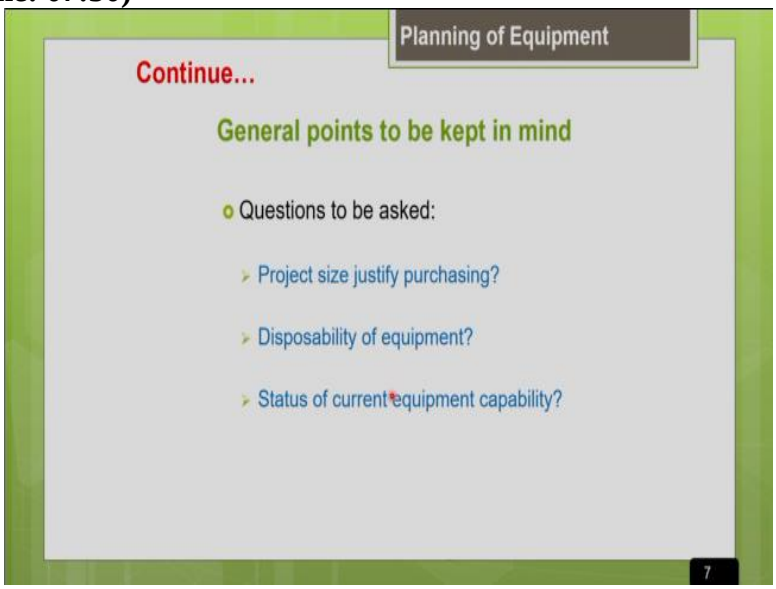

So, these are the general questions to be asked before planning for a purchase of any machine. Whether your project size justify purchasing of the machine? It is a very important question because whatever equipment you buy; the size of the equipment should fit into the size of your project that is the equipment cost should be fitting into the project cost. For a very small project I cannot go for a very high end equipment, it would not justify a purchase.

Similarly, you have to think about the disposability of the equipment also before you plan for the purchase. Say at the end of the useful life of the machine. So, you should be in a position to sell the equipment at a reasonable price, there should be buyers for the equipment. If the equipment is going to be commonly used in many projects, then there will be definitely buyers for the old equipment.

Then before buying a new equipment we should look into the status of the current equipment capability that means what is the current equipment capability? What is the productivity of the current machine? What is the cost associated with the current machine? Why should we go for the purchase of new machine? How a new machine is going to be better in terms of productivity and cost when compared to the current machine? So, this analysis you have to do before planning for the purchase of the new machine.

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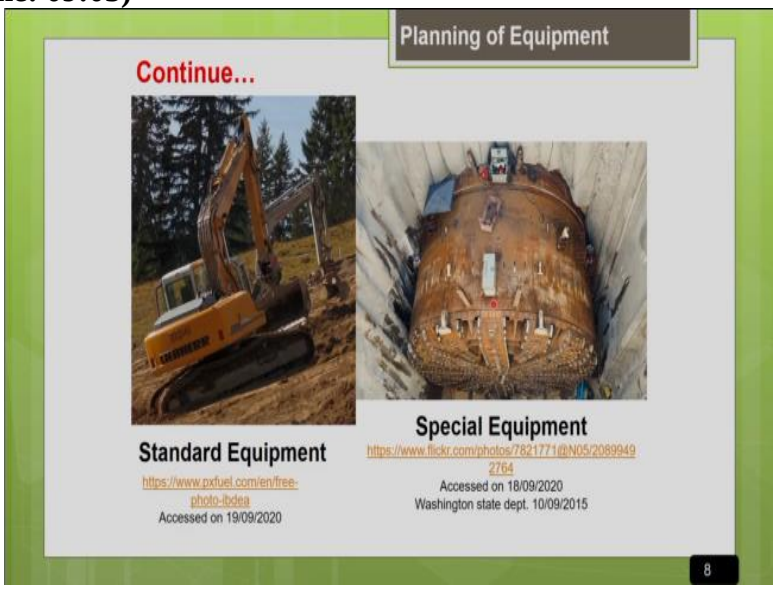

Based on utility of the equipment generally the equipments are categorized into standard equipment and special equipment. See standard equipments are just common equipments which are commonly used in so many construction projects. In so many construction project sites you can see these common equipments like a common earthmoving equipment bulldozers, your excavators. So, similarly concreting equipments, concrete mixer machines.

So, all these are common equipments which are used in so many construction project sites, but there are some special equipments which are of use only in some particular project sites. See, as I told you in the beginning itself, in the introduction lecture, we have achieved a lot of advancement in equipment technology. Like even if there is an equipment which is not existing

in the equipment market, but it is needed for a particular activity or particular project. It can be custom made for the particular project.

So, we have achieved that advancement in the equipment technology. So, those custom made equipments are called as special equipment. It is specially made custom made for the particular project or a particular activity in the project they are called as the special equipments.

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Now, let us look into the merits and demerits going for either standard equipment or special equipment. Let us compare the merits and demerits of both these options. So, when you go for the choice of standard equipments they are basically commonly available because there will be lot of manufacturers available for the standard equipments. Because it is used commonly in so, many construction project sites and its delivery will also be very quicker.

And if your equipment breaks down due to some reason the spare parts availability will also be very quicker. And another advantage is it can be used on more than one project that is also one of the advantages. So, your project will not get delayed due to the non availability of this machine or non availability of the spare parts because these are commonly easily available. And another important thing is at the end of the useful life of the machine.

It is easily possible to dispose it or sell it at a reasonable price that is also possible with the standard equipments. But the issues with the special equipment which are custom made only for a particular project is it may not be easily readily available. So, we have some waiting time for the machine. So, it is delivery may not be quicker because it is being custom made for a

particular project. Even if the equipment is going to break down the spare parts availability may not be easier.

It may get delayed and that delay may even affect the project completion. And at the end of the useful life of the machine, we cannot assure that there will be buyers for this special equipment, it is not being commonly used in all the projects. So, these are some limitations of the special equipment that is why before you plan for the purchase of this special equipment we have to work out the economics of the costs associated with the machine.

And the profit which are likely to generate by purchasing this machine whether there is likelihood of future projects which can make use of this special equipment. All these things we have to plan rigorously and then plan for the purchase of the special equipment.

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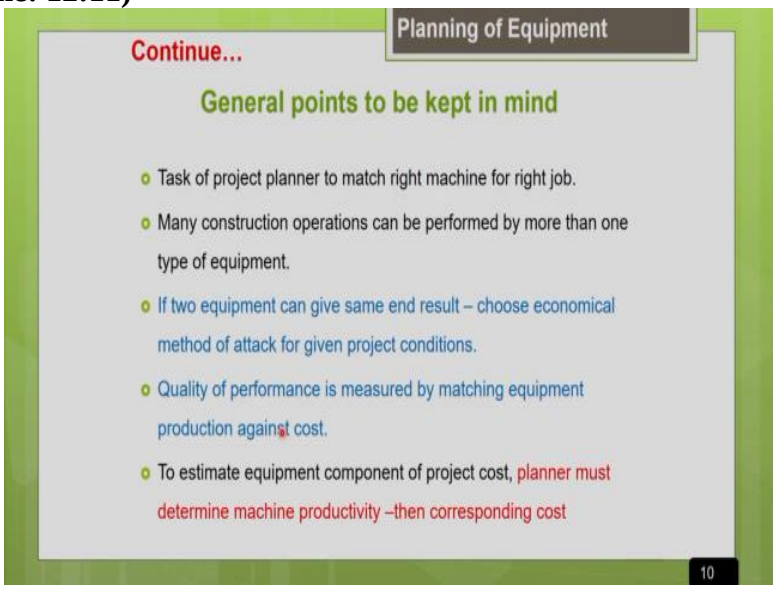

So, what are the other general points which are to be kept in mind while planning of the equipment? As I told you, the task of the project planner is to choose the right machine for the right job. It is really a challenging task now a days as there are so many options available even for the same job in the construction equipment market. So, many construction models are available even for a same particular function.

So, many construction operations can be performed by more than one type of equipment. So, now, how to make the decision? As I told you in the beginning of this lecture, we should go for the economical method of attack. If 2 equipment can give you same end result, choose

economical method of attack for the given project conditions. So, the project conditions also should be taken into consideration while selecting the equipment not only based on economics.

So, the economical method of attack in the sense whichever option whichever equipment or the combination of equipment is going to give you the maximum productivity at the lowest possible cost you have to select the particular option. So, the quality of performance is measured by matching the equipment production against the cost. So, this is a basic guideline, how we make the decision of the selection of equipment based on comparison of the productivity against the cost.

And another important thing is the knowledge of estimation of productivity and the cost associated with the machine is very important to make the selection. And also to estimate the equipment component of the project cost you should know how to estimate the productivity of the machine and the corresponding cost of the machine then only you will be able to estimate the equipment component of the project costs.

That is why knowledge of estimation of equipment productivity and the cost associated with the machine is very critical very important for any project planner or the project estimator. So, how to estimate the productivity and how to estimate the costs we are going to discuss in detail in the upcoming lectures.

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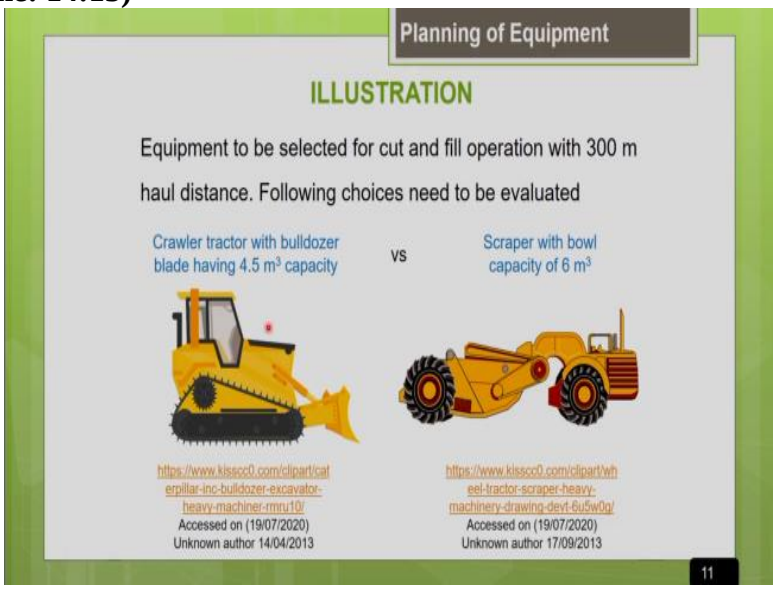

So, let us see a simple example on how to make the equipment selection. See, basically the job assigned here is to choose earthmoving equipment. Equipment has to be selected for cut and

fill earthmoving operation for a 300 meter haul distance. So, there are 2 choices given one is your normal the crawler bulldozer with an earth moving blade having 4.5 meter cube capacity and another option given is your scraper with a bowl of 6 meter cube capacity.

So now we have to make a decision whether to go for the bulldozer for the earthmoving operation or to go for the scraper for the earthmoving operation. Obviously, if you look into the haul distance, the bulldozer can give you maximum economic haul distance of only 100 meters but scraper can give you a longer economic haul distance up to 1000 meters. And also you have to look into the project condition also before making the decision. As of now let us just look into the economics alone to make the decision.

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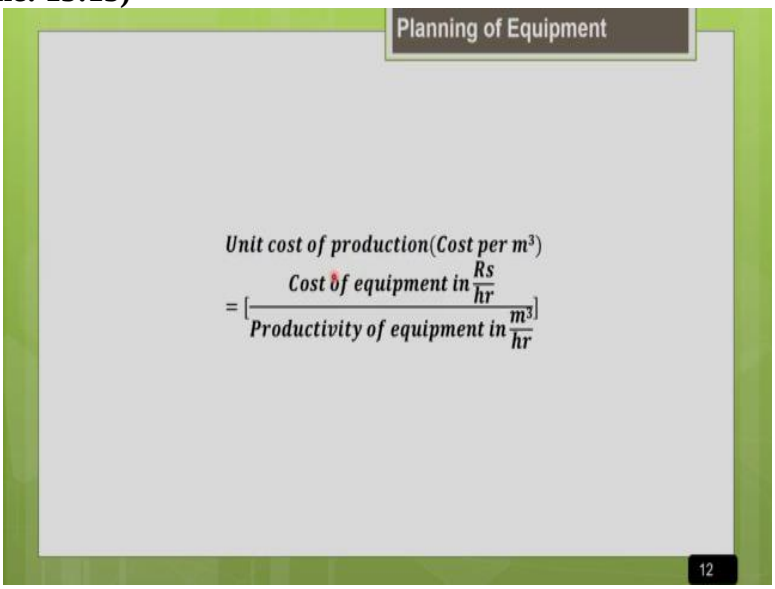

How to consider the economics of the both options? You have to estimate the unit cost of production associated with both the options. How to estimate the unit cost of production? Say what is the hourly cost associated with the machine you have to estimate. As I told you there are different components of cost ownership costs and the operating costs everything you should consider while estimating the cost of the machine and convert it into hourly cost and divided by the hourly productivity of the machine.

$$Unit\ cost\ of\ production(Cost\ per\ m^3) = \left[\frac{Cost\ of\ equipment\ in\ \frac{Rs}{hr}}{Productivity\ of\ equipment\ in\ \frac{m^3}{hr}}\right]$$

Say for example, earthmoving operation, how much volume of earth it is going to move per unit time? If it is going to be earth excavation operation, how much volume of earth it is going to excavate per unit time? If it is going to be concreting operation, how much volume of

concrete is produced per unit time? So, that is how to estimate the productivity of the machines. How to estimate a productivity will be discussed in depth for different types of construction equipment's in the later lecture hours.

So, as of now, you need to know how to estimate the unit cost of production associated with a particular job. So, for that you need to know the hourly cost associated with the machine and the hourly productivity associated with the machine. If you know that, you can estimate the unit cost of production associated with that particular job. Then you can compare the both options see whether I should go for estimating unit cost of production when we employ the bulldozer.

Estimating unit cost of production when you employ the scraper whichever gives you the minimum unit cost of production you have to go for that particular machine selection. This unit cost of production is a very important parameter because when you go for this bidding of projects when you plan for bidding, you work out the unit cost. This unit cost of your equipment also forms a part of the unit cost of your project that is way if you underestimate the cost of the equipment.

If you do not have a thorough knowledge of how to estimate the cost of equipment, you may underestimate the cost of equipment and you may overestimate the profit on paper finally, the contractor may end up in real problem. So, that is why, you should have a knowledge on how to estimate the cost of equipment because this will help you a lot when you plan for bidding.

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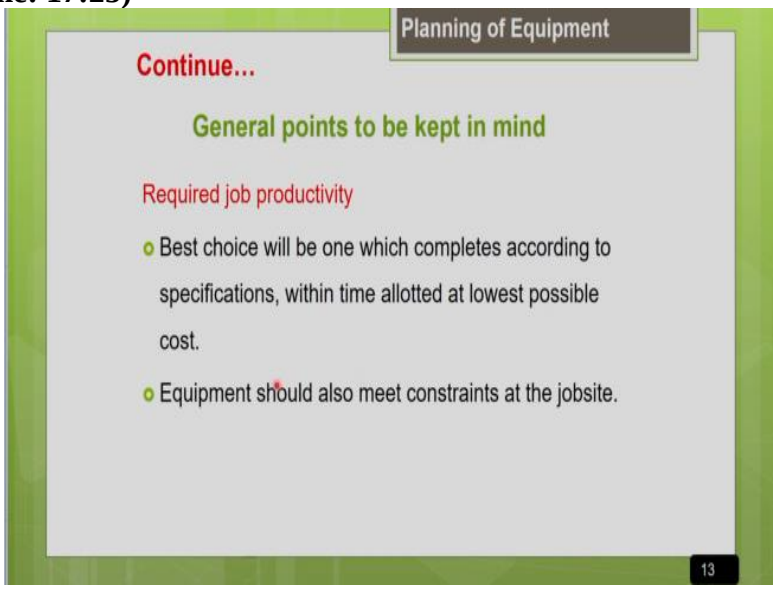

So, what are the other general points to be kept in mind? So far what we discuss is the importance of estimation of productivity of the equipment and the cost of the machine, how it governs the selection of the equipment. Now, you should see that what is the required job productivity for that particular activity? So, that information you can get it from your contract documents. Your contract specifications will let you know like what is the schedule of your project from the work breakdown structure.

You can know what is the time allocated for every activity? And what is the budget allocated for the project? So then you have to match your job productivity with the machine productivity. You have to select a measure of productivity to be matching with your job productivity. So, the best choice of equipment will be the one which will complete according to your contract specifications within the time allotted in the contract at the lowest possible cost, so that equipment you have to select.

So your contract specification is going to be your guideline for the selection of equipment, because that will only tell you what is your project time schedule what is the time allotted for every activity and what is the budget allocated you can get the detail only from the contract specifications and apart from all these things, the another important factor is your equipment selection should also consider the jobsite condition.

Whatever equipment you selected, it should meet the constraints at the jobsite there will be lot of constraints at your jobsite your underfoot conditions may be very poor, it may be a rocky terrain or it may be a steep terrain. So, jobsite may be in a very remote place where accessibility of the machine to the job site be very critical, your jobsite will be at a very high altitude the temperature will be very aggressive there it may be a very cold weather place. So, all these conditions will affect your equipment selection. So, all these things also should be taken into account apart from the economics of your= project.

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Now, having discussed about the general guidelines, which are to be kept in mind, now let us move on to the discussion about the important equipment selection practice. So the first one is your specific construction operation that is a basic factor, an important factor, as I told you your contract specifications in the contract documents that is only going to govern your selection that is going to decide your project time schedule and the budget allocated for that particular project.

And other than that there are different jobsite conditions like your underfoot conditions, your grade, how steep is your grade? And what is the working space limitations for your equipment and how was the excess of the equipment to the site? How is the site access? Other than that where is your site located that is going to decide your weather conditions like temperature, wind, rain, the altitude.

So, all these things will govern your equipment selection. So, apart from this, so, you have to also look for the other interdependent machines which are going to work with your proposed machine. So, machines which are working in team, the selection of one machine will depend upon the productivity of the capacity of the other machines and another important thing is what is the mobility required for equipment at your project site that will also govern your selection and how versatile you want an equipment to be.

So, these are all the important equipment selection factors. Now, let us look into all this equipment selection factors one by one.

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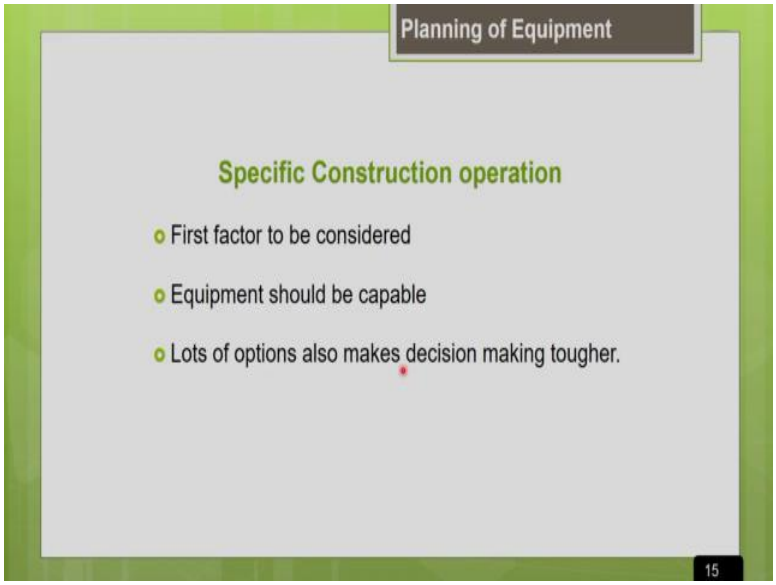

So, the first the selection factor is a specific construction operation. So, this is the first factor to be considered this is the basic factor. So, whatever equipment which we are going to select should be capable of doing that particular operation. Say for example, if we wanted to use an equipment for earthmoving operation, it should be capable of doing the particular earth moving operation that is a basic requirement of that particular equipment.

As I told you earlier a lot of options are nowadays available in the construction equipment market which makes the decision making very tougher for the project planner. So, in that case he has to work out the economics of different options and whichever equipment gives him the lowest unit production cost, he has to go for that particular option.

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Say let us see some examples see if you are going to select an equipment for earthmoving operation. So basically what do you mean by earth moving operation? What are the basic steps

involved? You have to loosen the earth first then excavate it, then haul it and then dump it. These are the basic steps involved in the earth moving operation. So there are different options of machines available for this activity, say I can go for a tractor with a ripper arrangement. So you can see this is a ripper which is attached to the rear end of the tractor.

So with this ripper, I can just loosen the earth so, this is one option available, I can use ripper first, then after that, I can go for a scraper after loosening the earth with the ripper, I can go for this scraper which is also an earthmoving operation, which can cut the earth and load it into the bowl. So, before cutting the earth with the scrapper if you are using the ripper, the job of the scraper will be very easier its productivity will increase.

So, I can go for a combination of ripper and the scraper this is one option possible or otherwise I can go for just a bulldozer with just an earthmoving blade, this is also possible. So, we can also compare the economic haul distance of both the machines. As I mentioned earlier, this one will give you a haul distance of 100 meter maximum and this one can give you a haul distance of up to 1000 meter maximum.

So, depending upon your job requirement, you have to make the choice and another thing is you can also go for a backhoe which is an excavator, greater depth excavation, you can go for this but the problem with this backhoe is it is a good excavator, but it is not a hauling machine. So, in addition to backhoe I need a hauling equipment like a truck. So, the backhoe will just excavate the earth and load it into the truck the truck has to haul the earth now you have to work out the economics of different combinations and whichever combinations will give you the least unit production cost you have to go for that particular combination.

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So, similarly, another example on hauling of earth as I told you the hauling of earth or you can either go for a truck, even the scraper what we saw in the earlier slide the scraper also can is good for a hauling distance up to 1000 meter it is economical. So, even you can go for a scraper for hauling of earth. So, there are different hauling machines available you can either go for a truck, which is the best hauling equipment or you can go for a front end loader.

So, for shorter distances, say up to 100 meters you can go for front end loader or you can go for a conveyor belt. So, productivity requirement is more so, everything depends upon your job requirement. So, you work out the options workout the economics of all these options and whichever gives you the lesser unit production cost go for that particular option.

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Similarly, another example if you see about the concrete placement, so, you are prepared your concrete in your concrete mixer machine, now you need to transport the concrete to your

formwork where it has to be placed. So, there are different ways different methods of placing the concrete either I can go for this chute in claim pipeline, to place a concrete, if the distance is going to be shorter it can go for a chute or you can go for a power driven buggy like this which can easily carry the concrete from the mixer machine.

And take it to the formwork or you can even go for a pumping method which is more popular. Concrete pumping is commonly adopted for placement or you can go for a conveyor belt like this. If the placement requirement rate, the rate of placement needed is very high or they can go for even crane with buckets, if the concrete to be placed at a greater height, then I have to go for crane with concrete buckets even we can even go for a helicopter with concrete bucket depending upon your job site condition.

If the job site is not accessible by other machines, then you have to go for the option of even helicopter carrying a concrete bucket. So, there are different options possible for placement of concrete, you have to work out the economics of all these options, whichever is more economical for you, then you have to go for that particular option, that is why the productivity and the cost will be the guideline for you for the selection of the machine.

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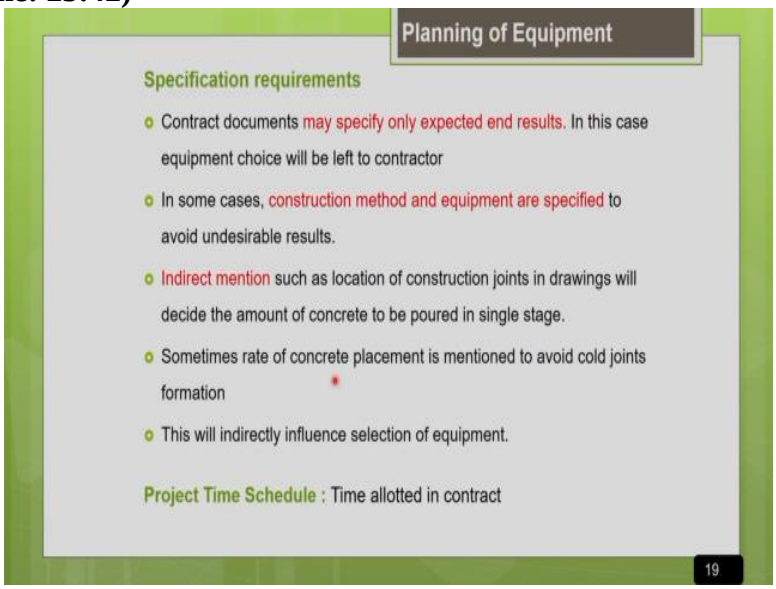

So, the next important factor which is going to govern the selection of the machine is your contract specification guidelines. So, what are all the guidelines which are specification in the contract documents, that is a very important guideline. But the thing is, as I told you, your contract document is only going to define the exact project time schedule and the time needed

for every activity is going to be dependent on the specifications given in your contract documents. And also the budget also is clearly mentioned only in the contract documents.

So, that is going to be important guideline for the selection of the machine, but the contract documents may not be sometimes clear some contract documents or specifications may specify only the expected end result say for example, they may specify for a particular concrete column, you have to go for M 30 grade of concrete with a slump of say 75 mm that may be the only specification.

So, there may not be any mention on what is the methodology to be adopted, how the concrete is to be made, what type of mixer machine you are supposed to use and what is the method of placement to be followed may not be mentioned. In that case, equipment choice methodology everything will be left to the choice of the contractor, but in some cases, your construction method and the construction equipment or specific very clearly in the contract documents to avoid undesirable results.

Say for example, they mentioned like M 30 grade of concrete with a slump of 75 mm you have to go for ready mix concrete and you have to go for pumping method for placement and this should be the rate of placement of the concrete what is the value everything will be mentioned clearly to avoid undesirable results, but in some contract documents, you can see that mentioned maybe indirect, indirectly it may be mentioned say such as location of the construction joints in the drawing will indicate the amount of concrete that is to be poured in 1 single stage.

By looking into the construction drawings, you can see the location of construction joints that will indicate the concrete that has to be placed in 1 pour. So, that will indirectly govern the selection of your size of your concrete mixer machine. So, what is the size of the mixer machine needed or how many number of mixer machines are needed, it depends upon the volume of concrete that is to be produced 1 pour.

So, in some cases, if they wanted to avoid the cold joint formation, they will clearly mention the rate of concrete placement. So, that will be also clearly mentioned. So, the specifications varies, the way of measuring varies from there document to document, but it will give us a guideline on how to select a methodology and the equipment.

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So, another important thing apart from all is economics. So, which we need to consider is the conditions at the job site. So, the real site condition that is very important factor for selecting your machine, say the underfoot conditions that is going to decide the type of mounting needed for a machine say the terrain is going to be very rocky or it is going to be very sandy. In that case, it is not possible for us to go for this kind of wheel type machine or rubber type mounted machine.

We have to go for crawler type or track type, which will have a broad contact area, better traction better stability. So, for poor underfoot condition, people prefer crawler mounted machines, because that will give you better traction or stability. So, the underfoot condition is going to decide the mounting of the machine. So, another important thing to be noted is rolling resistance that will govern the selection of machine, what is this rolling resistance?

So, when your machine is moving over a particular road surface, how much resistance the particular road surface is going to offer to the movement of the machine. So that is called as the rolling resistance. So if your underfoot conditions are very poor, if it is going to be a rocky terrain or if it is going to be a very muddy terrain, so the amount of resistance offered by the haul route to the movement of vehicle will be very high.

So in that case, you have to go for machines with greater horsepower capacity, because we need more power to overcome the underfoot conditions. So, after overcoming the rolling resistance, the remaining power is only available for the machine to do the actual job of either

excavation or towing the load. So, first we have to overcome the underfoot conditions after that what is the remaining power is only available for the productive job of either excavation or for towing the load.

So, we have to see if the underfoot conditions are very poor select the machine with a greater horsepower capacity, so, that you can overcome the rolling resistance in the project condition and you can keep your machine moving and do your job productively or efficiently. So, what I am trying to say here is the project condition will govern the selection of your capacity of the machine not only the mounting, but also the capacity of the machine.

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Another important guideline which we should keep in mind is we should always maintain the haul roads, there are so, many equipment's to maintain the haul road, like either you can go for a grader or you can go for a compactor. So, you should maintain the haul roads clear all the short rocks so, that you can increase the travel speed of your machine. So, if you can increase the travel speed of your machine, the cycle time of the machine will be reduced.

So, your productivity will increase so, your total project cost gets reduced. So, that is why we should spend some efforts for maintenance of the haul roads in the project site that will really help you to reduce the cost of your project.

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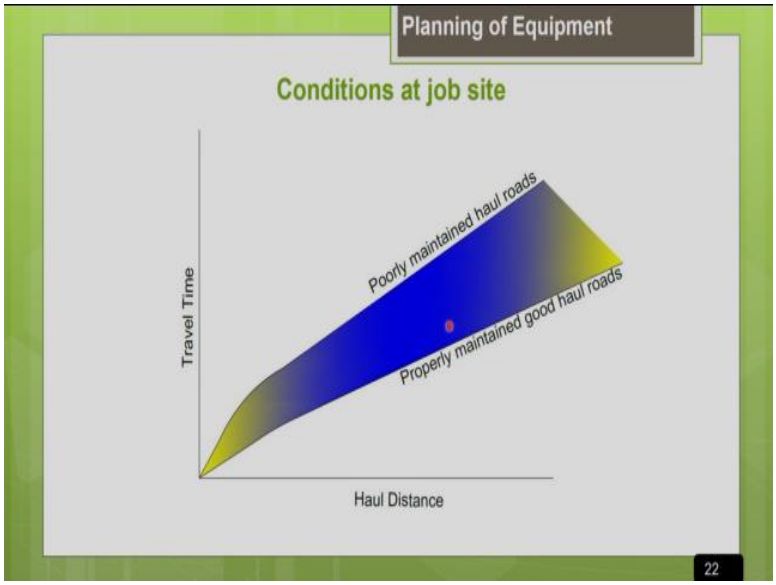

So, this graph shows you the difference in the travel time of a vehicle which is running over a poorly maintained haul road and another vehicle running on a properly maintained haul road you can see there is a significant reduction in the travel time of the machine. So, this will definitely influence or affect the productivity of the machine and the cost of the project.

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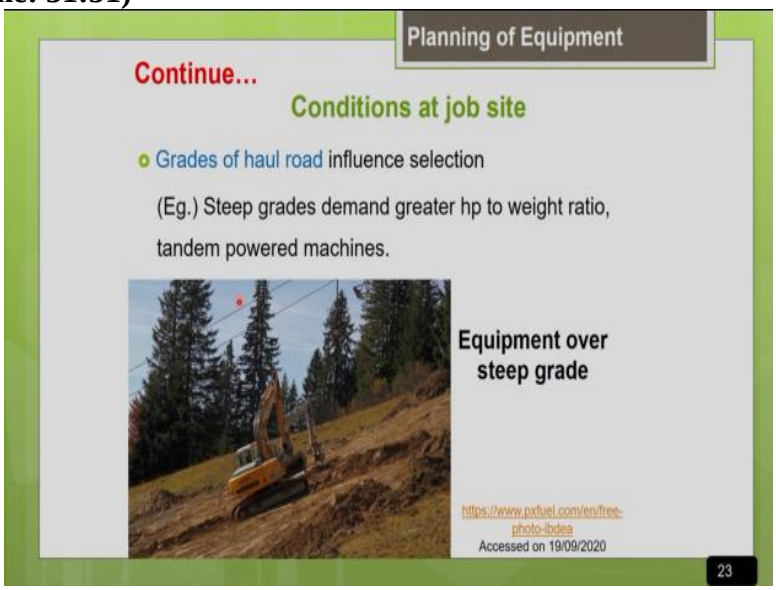

So, another important thing, which you have to take into account, is your condition at the job site, the steepness of the grade. So, sometimes your machines may have to work on a very steep terrain. So the slope may be very steep. So, your machine has to climb the particular slope and work. So, in that case, as I told you earlier, we have to go for a machine with a greater horsepower capacity, because the machine has to overcome the particular grade resistance and then only you can do the actual job.

So, you have to select your machine with a horsepower capacity, so that it can overcome the grade resistance it can climb the particular slope and do the required job. So the steep grades demand greater horsepower machines and on steep grades, we have to go for tandem power machines. So what are tandem power machines? Basically there are some special machines where all the axles are powered all the axles of the machine will be powered.

So, there will be twin engine component which will deliver more power to the machine. So, particularly for tough conditions like this like steep terrain or poor underfoot conditions, if you go for tandem power machines, you can have a very high productivity. So though the cost of this machines may be higher, but the production it will result in a higher productivity. So, your total project cost gets reduced. So you have to work out economics and go for the selection of these kinds of specialized machines for the poor project conditions or tough project conditions.

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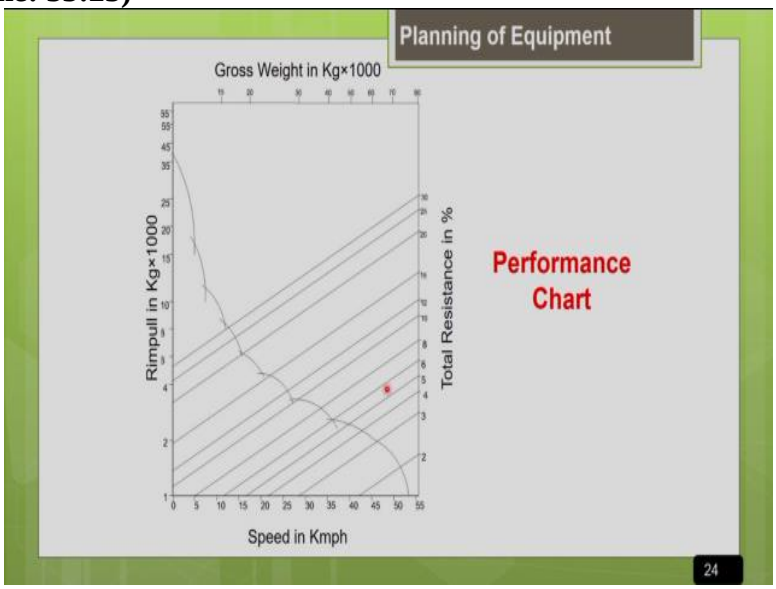

So, this graph shows you a typical performance chart. So, these kinds of performance charts you can find in the equipment handbook, supplied by the equipment manufacturer, so, equipment manufacturer will provide these kinds of performance charts for every model of the machine produced by him. So, by looking into this performance chart, you can get an information on what will be the speed of the machine for a given project condition say for this particular underfoot condition.

And for this particular steepness of the slope for this particular grade, grade percentage. So, for this particular rolling resistance, that is a project condition actually. So, for this total resistance, what will be the speed of my machine I can get from this graph. So this chart I will explain it

in detail in the upcoming lecture or when we discuss about engineering fundamentals of earthmoving operation.

So I am just trying to introduce you the topic that advantage of this performance chart. So, this performance chart shows that the project condition is going to govern your machine selection, because a project condition the total resistance, the rolling resistance, the grade resistance, which depends upon the underfoot conditions, that is going to decide the speed of your machine. So if you want to the greater speed, in a very poor underfoot condition, you have to select a machine with a greater horsepower capacity. So the underfoot conditions or the project site condition is definitely going to affect your selection of your machine.

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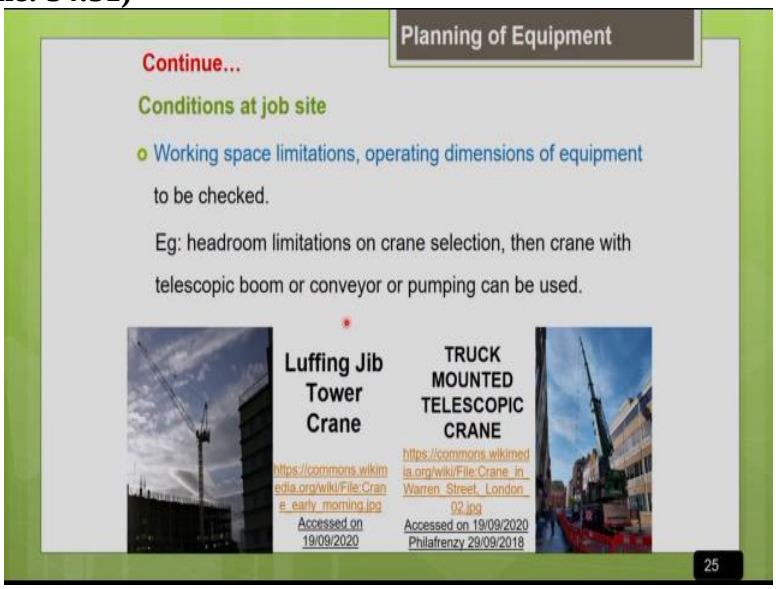

So another important thing which we need to consider is your working space limitations. And you have to look into the operating dimensions of the equipment which you are planning to select so, whether there are sufficient spaces for the equipment to fit in your project site. So, that is a very important factor to be decided before planning for the purchase of a machine. So, you have to visit your project site and you have to see whether there is any working space limitation or working space constraint with respect to the equipment size.

So, these kind of issues very often we face with respect to crane selection, when you select your crane, we have to see whether there is proper overhead space availability for the movement of the boom of the crane. So, particularly when you are working in a congested sites like in your project site is near an already existing structure. So, when the site is very much congested, you have to analyze whether there is overhead space availability or not.

So, as I told you this beginning of the lecture, there are different models of cranes, there are some cranes, where the boom is fixed, you cannot change the angle of inclination of the boom of crane. So, those cranes are called as horizontal boom crane. So, those cranes are not possible to be used in the congested sites, because the availability of space for the movement of the boom of crane may be limited.

So, in congested sites, they have to either go for this kind of luffing jib crane, you can change the angle of the jib of your crane according to your requirement. So, this is one advantage to work in the congested side. Now, there is working space limitation working space constraint. Similarly, I can go for a telescopic crane, we will be discussing about different types of cranes, different characteristic features of cranes and productivity estimation of cranes in the upcoming lecture.

This is just an introduction on how to select the machine with respect to the working space limitation. So, coming to this truck motor telescopic crane, you can see it is just like a telescope, you can just extend or retract the length of the boom of the crane. So, according to your requirement, you can extend the length of the boom or retract the length of the bottom of the crane. So, in congested sites, these kind of cranes will be very much helpful than going for fixed horizontal boom crane.

So, according to your space limitation, you have to go for the selection in worst case, and you can even drop the option of crane when there is the space constraint, you can go for the pumping method. Next, for example, if you are going to plan the selection crane for concrete placement, you can go for a pumping method for the placing the concrete or even you can go for a belt conveyor. So, you can work out the economics of all the options as well as consider the site constraints and make the decision.

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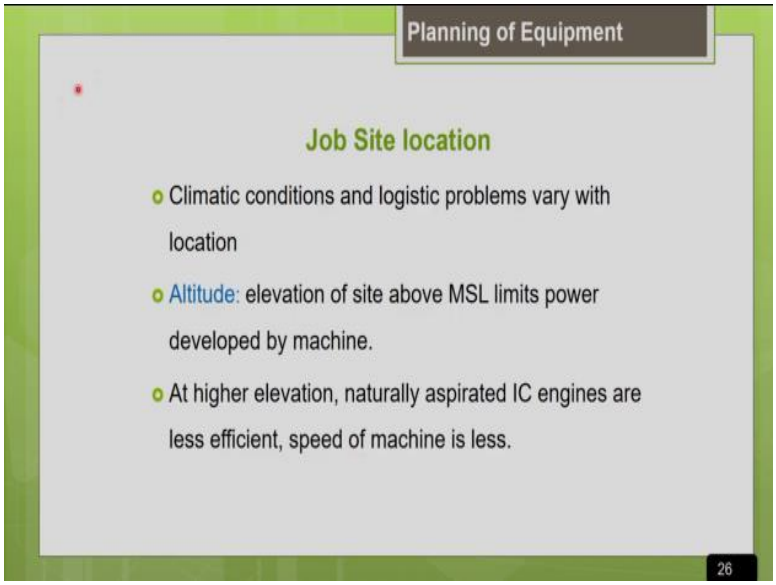

So, far we discuss about the job site conditions now we are going to see how the job site location is going to affect the selection of the machine. So, that is basically it is going to affect the climatic conditions of the place and other logistic problems involved with the mobilization of the equipment at the particular site. So, all these things are dependent upon your job site location.

So, one important factor to be considered is the altitude of your job site say all these machines, most of the machines what we use in the construction project site, they are IC engines internal combustion based engines, these internal combustion based engines rating, there is a horsepower rating is done at standard conditions say at a standard temperature and its standard atmospheric pressure say for example, SAE Society of Automotive Engineers.

So, there are prescribed the rating of the machines, but the standard temperature of say 15.5 degrees Celsius and atmospheric pressure of 103.3 kilo Pascal. So, the horsepower rating is valid for that particular standard temperature under pressure. So, if your machine is going to work at a place where the temperature is different from the standard condition or the atmospheric pressure is different from the standard condition, then you may not be able to realize the same efficiency as prescribed by the manufacturer.

So, your horsepower at a different condition may be lesser than the value prescribed by the manufacturer. So, as I told you, the internal combustion engines for its efficient operation, the fuel to air ratio has to be maintained it is very critical for the combustion mechanism. So, if your job site is located at a very high altitude, say above the mean sea level, your atmospheric

pressure will be less. So, when the atmospheric pressure is less obviously, the density of the air is going to be less.

So, the amount of oxygen which is available for the combustion mechanism is going to be reduced. So, in that case, we will not be able to maintain the fuel to air ratio for the combustion mechanism of the machine. So, in that case obviously, your efficiency of the machine is going to get affected. So, this is how the altitude of your location is going to affect machine performance, because at higher altitude, the availability of air, for the combustion mechanism gets reduced.

So, the engine would not be able to perform at the same efficiency as a machine at the mean sea level. So, you would not be able to realize the efficiency prescribed by the manufacturer. So, in that case, what are we supposed to do? So, that is what is mentioned this slide at higher elevation naturally, aspirated IC engines are less efficient. So, since they are less efficient, and the speed of the machine will also be lesser. So, how to overcome this problem?

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So, particularly for the higher altitudes, which are very much above the mean sea level, so, there are some specialized arrangements, the possible in the machines like a turbochargers so, these turbochargers can be fitted to the equipments this will facilitate to maintain the fuel to air ratio, even at higher altitude. So, you can see this mechanism of the turbocharger the blue color indicates the air movement.

So, there will be a compressor arrangement which will help you to artificially and supply the air and maintain the fuel to air ratio for the efficient mechanism of the machine even at higher altitude, where the density of air is less. So, when you are going to work at higher altitude, go for these kinds of special machines with turbo charges, otherwise, you have to go for either larger equipment or more number of machines to compensate the loss of efficiency at a higher altitude. So, depending upon your altitude you have to make your equipment selection, so, that the efficiency of the machine would not be affected even at higher altitude.

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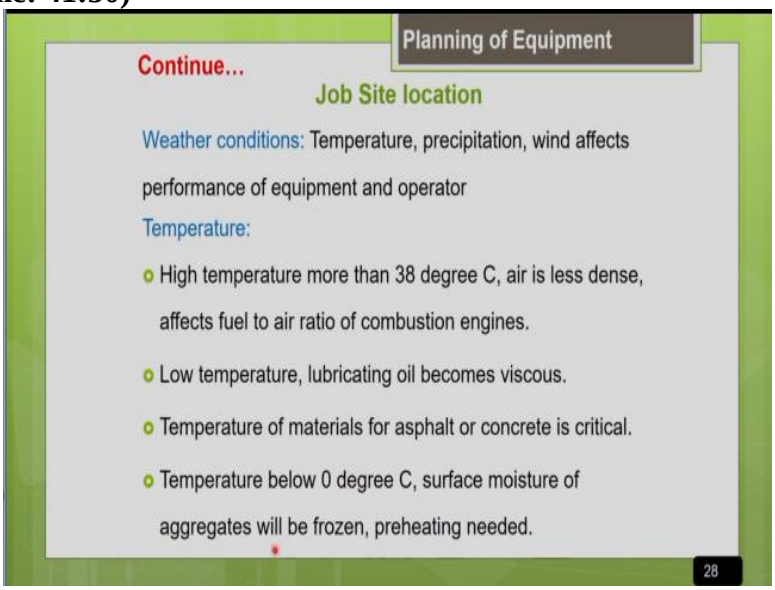

So, another important thing which you have to keep in mind is your job site location is going to influence the weather condition obviously, the climatic condition depends upon the location of your job site, your temperature, rainfall, wind, everything is going to affect the equipment performance, even the operator performance and also the equipment selection. So, in your job site, the temperature is very high.

So, in that case, obviously, you will face the same issue as we faced with the higher altitude location, you can see that as the temperature increases your density of air will reduce. So, the amount of the fuel to air ratio which is needed for the combustion mechanism gets affected in places with high temperature. So, in that case, you have to select a machine with a turbocharger so, that you can maintain the fuel to air ratio without affecting the efficiency of the machine.

Similarly, a lot of issues you can face in the low temperature places also. So, in low temperature like your lubricating oil in the machine, may become viscous, so, you should have some preheating, I mean heating facility inside the machine to heat a lubricating oil to maintain the

viscosity. So, particularly for the places where the temperature is freezing cold weather countries you have to look for the machines with special arrangements to maintain the viscosity of the lubricating oil some heating arrangement.

And another important thing to be noted is your material like concrete or asphalt, the working range of the temperature is very critical. So, you have to maintain its temperature if that particularly in the cold weather, if you say like before preparing the concrete. So, the materials are not stored properly, if they are stored in open spaces, if the aggregates get frozen, so, the surface moisture of the aggregate may get frozen.

So, in that case, we cannot directly mix your aggregate and cement and water for preparing the concrete. So, in those places, you should have some facility in the mixer machine to preheat the material to preheat water preheat the aggregate then you prepare your concrete. So such kind of pre heating facility is needed for cold weather countries. Similarly, your asphalt it is a thermoplastic material.

Obviously, its viscosity is totally dependent upon the temperature. For a very cold weather, you can see that it is viscosity will be significantly affected. You would not be able to work with asphalt. So you have to maintain the working range of this particular material like asphalt or concrete by using some thermally insulated devices. So, you have to protect this material from the severe climatic conditions in places with aggressive climatic conditions.

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So, this picture shows you an insulated truck which is used for transporting the bitumen. So, this will help you to maintain the temperature of the bitumen as I told you, the working temperature of the bitumen is very critical. So, you have to maintain it at temperature similarly, even your ready mix concrete trucks you can go for insulated RMC trucks particularly in the cold weather countries in order to maintain the working temperature.

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So, another important thing the same way you can say that your heat and wind will affect the concrete performance. So, that is what we discussed in the earlier slide also, if your concrete is going to be exposed a very high temperature and you can see that it will result in the evaporation of water from the concrete. So, even during the process of making of concrete, it may result in evaporation, if it results in the evaporation, it will affect the workability of your concrete.

So, in those high temperature places, you should have a provision to protect the concrete from the high temperature even during the process of making of concrete and similarly, after the concrete is made, if it is subjected to a very high temperature. So, what happens it will result in loss of water from within the concrete to outside environment. So, that may result in a shrinkage cracking of concrete it is called as plastic shrinkage cracking.

So, in those cases, we should have some facility to protect the concrete from high temperature or high wind velocity even a higher wind velocity may result in the loss of water from the concrete. So, that may result in cracking of concrete so, in those places you should also facility to protect the concrete during the making of concrete and even after the concrete is made.

It should be properly protected for the severe weather conditions and you should start the curing of concrete as early as possible in aggressive conditions to protect the concrete from the cracking of concrete. And another important factor which will affect the selection machine particularly the crane selection is a wind velocity. So, the lifting capacity of your crane will depend upon your wind velocity in places where the wind velocity is going to be very high, the lifting capacity will be significantly reduced.

So, how much a crane is going to lift it depends upon the speed of the wind prevailing there. So, there are some standard guidelines, which help you to make the selection of the capacity of the crane depending upon the wind speed. So, you can go through those guidelines. So, basically the wind speed is very high say more than 50 kilometer per hour or more than 55 kilometer per hour you have to stop the crane operation.

So, it is not safe to operate the crane when the wind velocity is very high, because so many crane accidents that happen when we try to operate the crane at high wind velocity it will result in entire toppling of your crane. So, one thing you have to keep in mind is your wind speed will decide your selection of your crane capacity in places where the wind speed is likely to be high you have to select the crane with a larger capacity so that you can counteract the wind speed. Now let us say what is the effect of the rainfall on the selection of the machine?

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So, in some places you can see that for most of the months there will be continuous heavy rainfall. So in those places obviously the terrain will be very poor like it will be having the poor underfoot conditions with a very high rolling resistance the terrain will be very muddy. So, as

I said earlier in those cases, we have to select the machine with the proper mounting and with the better horsepower capacity so that it can overcome the rolling resistance in the poor underfoot conditions.

So, the same thing it will apply for the snowy terrain also in snowy terrain, we can see that the traction for the rubber tire mounted machine will be very poor. So, in that case, we have to go for the crawler type mounted machines, crawler mounted machines, so that it will have better traction. So, the underfoot conditions influences the selection of the mounting of the machine as well as the selection of the horsepower capacity of the machine. So that it can overcome the rolling resistance and it will be able to do the job productively. So, the next important factor is the power source.

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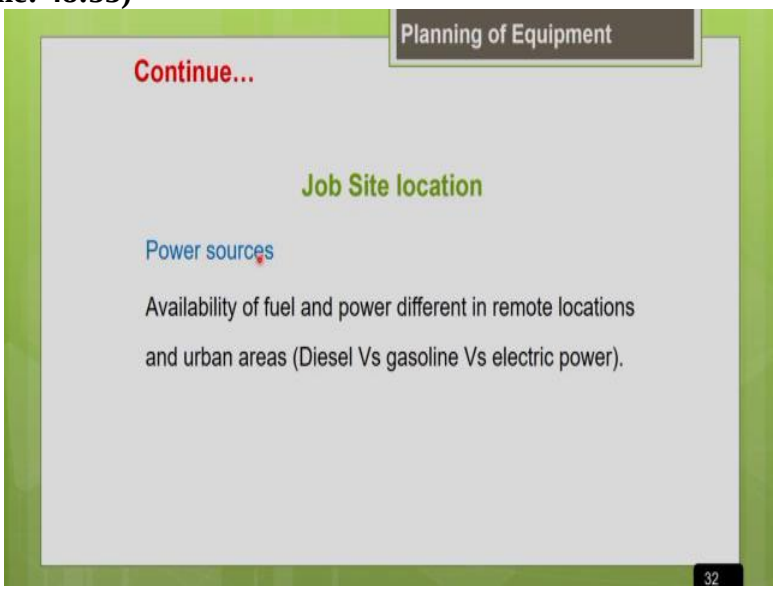

So far we have discussed about how the job site conditions and the job site location how it influences the selection of the machine. So, now we move on to the next factor affecting the selection or machine that is the power source availability. So, the machines which we use at the construction site may be either operated with diesel as a fuel or it may be the gasoline operated or it may be based on electrical power operated.

So whatever may be the mode of source of fuel. So, first we have to check whether that particular fuel availability is possible in the job site location, because availability of fuel and the power are different in remote locations and urban areas. So, the fuel availability may be easier in the urban areas when compared to remote locations. So, if your job site is located in

a remote location, we have to first check for the availability of the particular fuel needed for the machine.

So, there are always provision to store huge quantities of the fuel required for the equipment, but still, we have to make sure that the since the project is going to happen for a longer duration, so, it is convenient to select an equipment for the particular equipment, the fuel should be available in the particular site location. So, it is always advisable to select equipment on such a basis of the fuel required for the machine is available in the site location.

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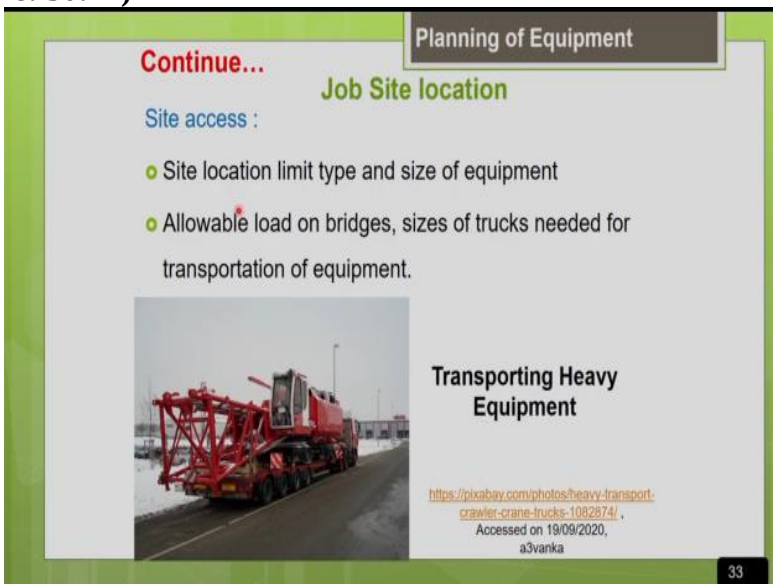

So, the next is about the influence of the site access, on the equipment and the selection. So, many cases you can see if the project site is in a very remote place, it will be really challenging to mobilize the equipment to the particular site. So, the site location will limit the type and the size of the equipment. So, if you have to mobilize a heavy equipment to a very remote site, we have to check whether there are availability of the proper access routes or the haul routes to mobilize equipment to the particular remote site.

And also we have to check on what is the allowable load on the bridges, all these things need to be checked before deciding that particular equipment for the particular site location. Because if it is going to be heavy end equipment like say for example a very big crane, you may need so many trailers on to the transport one particular equipment to the project site. So, generally when we go for a very bigger equipment, heavy equipment.

Obviously, we will get the benefit of higher productivity, but the mobilization costs will also go up. So we have to work out the economics before selecting the heavy equipment because it is associated mobilization costs will be definitely higher. So, as I discussed, just know, you have to look into the site location, wherever the access roads to the site is proper for the mobilization of your machine to that particular site, then accordingly only we have to make a selection of the machine for that particular site location.

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So then here we can see a picture here a trailer is the transporting heavy equipment to the project site.

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So far, we discussed about how the job site conditions and the job site location, how it influences the selection of the machine, as well as the efficiency of the machine. So we have discussed those factors. Now, move on to the next important factor about balancing

interdependent machines, how it is going to affect the selection of your machine. So, generally in many project sites we can see that many machines will be working together.

So when the machines work together, they should have compatible productivity or compatible size. So that cycle time is not wasted much see in this picture, you can see an excavator and a truck working together. So everyone knows about this excavator this is a backhoe, it is very good in excavating the earth below the ground level, but its mobility is very poor. So, it has to depend upon a hauling equipment like a truck to transport the earth. So, both these machines work together.

So, when they work together, their size should be balanced. So, that the productivity will be efficient, so that the entire process will be efficient, you can reduce cycle time. So, you cannot go for a very small truck for a very big excavator or you cannot go for a bigger truck for a small excavator in both the cases that will be wastage of cycle time or idle time of the machine to reduce idle time and to avoid the wastage of the cycle time try to balance the sizes of both the machine.

So general guideline is, you have to go for the truck, which has a capacity of 4 to 5 times the bucket capacity of the excavator. So, in that case, the entire process will be efficient, the productivity will be balanced. So, this guideline is devised based upon the past experience, similarly, you have to balance a number of machines also say for example, the how many excavators and how many trucks you may need for the particular operation, you need to balance depending upon the cycle time of the truck and the cycle time of the excavator.

We will be doing in the upcoming lectures on how to do the balancing of interdependent machines there will be some solved illustrations also to throw more light on that particular topic. So now I am just introducing the topic to you like when planning of the equipment we should keep in mind that if the machines are going to work in a team, then the size of those machines should be balanced and the productivity also should be balanced so that you can avoid the wastage of the cycle time.

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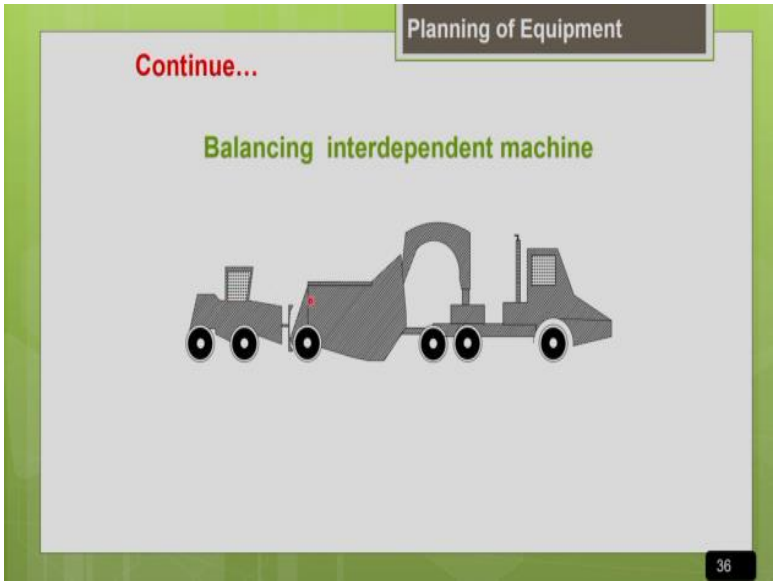

So, this is also another example of how the interdependent machines are involved in the project side. So this is just a schematic picture showing a bulldozer which is pushing a scraper, the scraper is leading end and bulldozer is the rear end. So, you can see that generally this scrapers also earthmoving machine as known to everyone. So, it has a bowl with a cutting edge at the bottom.

So it can cut the earth and fill the bowl. So, during this loading operation, we can supplement the loading power of the scraper with the help of another machine that is the bulldozer. So, the bulldozer is acting like a pusher here that is why we call the bulldozer is a pusher it helps to supplement the loading power of the scraper it is assisting this machine. So, when these 2 machines are working together to enhance the productivity of the scraper.

We have to balance the size of both the machines for a bigger scraper have to go for a bigger size bulldozer so that the productivity of the scraper will be enhanced the same way as I discussed earlier how many of the scrapers are going to be served by 1 pusher so, we have to balance it based upon the cycle time of the scraper and the cycle time of the pusher. So, the number of scrapers and the number of pushers needed for the particular job, we have to work out economically.

We have work out to the economics involved in this particular process and decide and balance the number of scrapers and number of pushers needed for a particular job.

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So, the next important factor is it the mobility required. So, it depends upon the project additional actual activity. So, what is your mobility required with respect to equipment during the particular activity? Or what is the level of mobility needed to move the equipment from one activity to another activity? Or what is the level of mobility needed to move the equipment from one project site onto the project site?

So, depending upon the requirement of the project condition, so, you have to decide the mounting of the machine. So, this picture shows truck mounted concrete pump with a boom. So, basically we prefer this equipment in sites which are very much congested where we cannot even lay pipelines on the ground for conveying the concrete for placing the concrete if you are not even able to place the pipeline into the ground because of the congested site you can go for this option.

So, this is basically a concrete pump mounted on the truck with a boom arrangement just like a crane. So it helps to place concrete at the required location. So, in congested sites, where the mobility is needed, you can go for this particular option. So like this, there are different options available depending upon the requirement and depending upon the conditions at your site, you have to go for the selection of your machine so, now a days people prefer to go for versatile machines.

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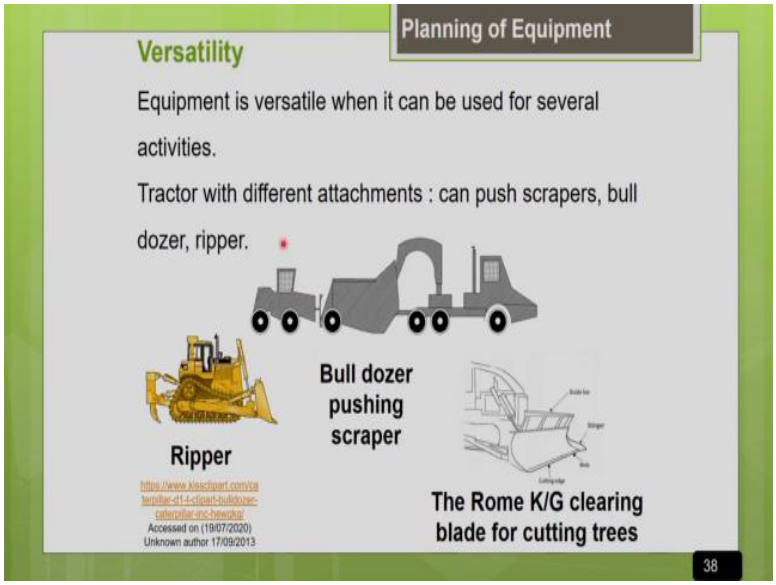

Versatile machines in the sense; equipment is called as a versatile machine when it can be used for several activities in the same project site. So then we call it as a versatile machine. So the best example is your tractor just by changing the attachments, you can use it for different applications say just be fitting earthmoving blade, I can use it as a bulldozer for earthmoving operation.

So if I fit a shank like this, it can act like a ripper for loosening the earth or for even cutting the rock, sometimes weaker rocks you can go for a ripper for cutting instead of drilling and blasting which is going to be very costlier. Ripper is cheaper when compared to the drilling and blasting process and even this can be used for cutting or ripping old pavements, there are different applications, just by changing the attachment you can go use it for different applications.

Similarly, you can use the special blade called is Rome K/G blade, which is specially designed for cutting trees, it is a very efficient way for cutting trees, just by changing the attachment you can use a bulldozer for cutting the trees. The same way as I described just earlier, the bulldozer can be used for pushing or assisting the other machines for towing other machines or pushing other machines you can use the bulldozer. So hence the tractor you can call it as a versatile machine, because by changing the attachments, you can use it for different applications.

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So the next one is the front end the loader, you can see the loader with the different attachments. Just for different applications you can change the attachments and make it more versatile. So you can see the loader with the front end bucket here. So as everyone knows, the loader can be used as a hauling equipment for a very short distance of say, up to 100 meters and it is good at excavating material at or above the ground level.

This is the best equipment this is the best choice. Depending upon your material type you can change the attachment say for example, if I am going to use this loader in a query for handling the short rock, the blasted rock pieces if you want to do and handle it with the loader, then you can go for an attachment with a rock bucket that has a V shaped cutting edge, so with this bucket again, the handle the rock pieces.

Similarly, if I am going to use this loader for handling precast elements, as a lifting device, then I can go for this fork lift attachment. So with this, I can use it for lifting purpose. Similarly, if I am going to use this loader in congested place say for example, I am working on a road, I am doing some digging or dumping job on one side of the road. So, where I prefer side dumping to be done, instead of front dumping, I can go for this kind of attachment and go for side dumping. So, just by changing the attachments, I can use it for different applications.

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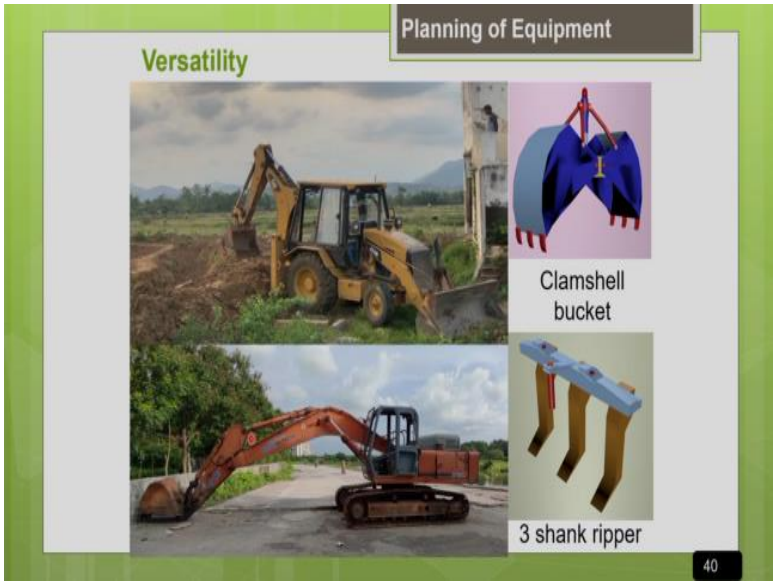

Similarly, you can see this combination this is a combination of a front end loader, a loader and backhoe combination. So, you have the loader at the front end and backhoe at the rear end. So, loader as I told you, it is good for it is efficient in excavating at the ground level or above the ground level and this backhoe is efficient in excavating below the ground level. So, both the jobs can be done with the same machine so, it is more versatile.

And similarly, this excavator, you can see that by changing the attachment like, you can go for this clamshell bucket. So, just by changing this attachment, you can use it for deep digging. Similarly, I can go for this kind of 3 shank ripper and use this excavator for cutting the earth or cutting the rock. So, whatever may be the application accordingly so, you can see like, just by changing the riging devices or changing the attachments, I can use the same machine for different applications.

Another thing to be mentioned here is this excavator is very commonly used for the excavating and for pipe trenching in pipe laying operation, because the same machine you can use for the complete job, say for example, if you wanted to go for the pipeline operation, they use this as an excavator with a bucket equal to the width of the trench. So, then they first excavate the trench so, once the excavation is done, then they change the rigging they go for an attachment, so that they can carry the pipeline.

So, then they carry the pipeline and place the pipeline in the excavated trench with the same machine, then they change the attachment and use this excavator for the filling the trench within the soil. So, the same machine can do the complete trenching and pipeline operation. So, that

is how it is more versatile. So, far we have discussed about different factors, which affects the equipment selection process.

So, I will just summarize like the basically from this discussion that we know that the important factor which affects the equipment selection is your productivity and the costs associated with the machine and you have to look into the contract specifications to know what is the actual job productivity requirement, accordingly you have to select the machine with the corresponding matching the productivity.

And you have to also check that your costs associated with the machine will fit into the project cost. So, other than these things, your job site conditions or the job site location also influences the outcome or selection of the machine significantly.

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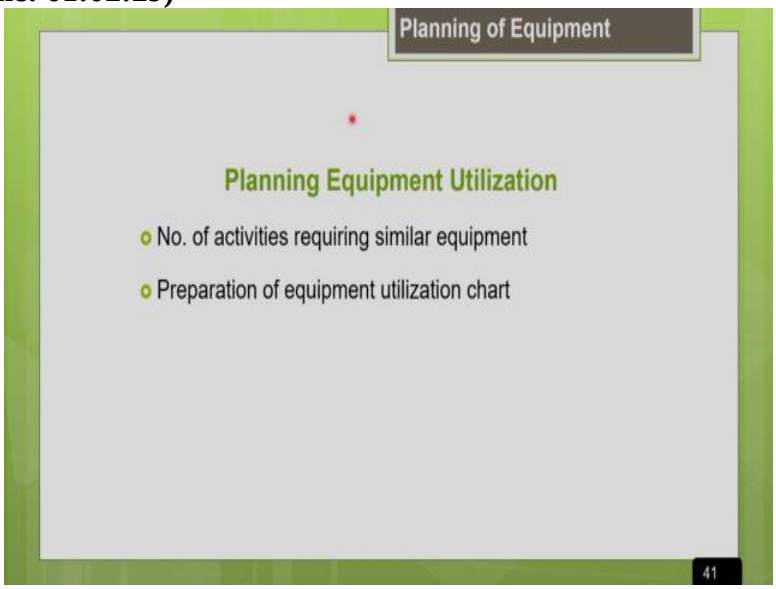

So, now let us move on to the next part of the planning process of the equipment which is the planning of equipment utilization. So, we have invested a huge amount of money in the machine. So we have selected the machine we have purchase a machine. So we have invested huge amount of money in the machine. Now it is our responsibility to make sure that the equipment is utilized in an optimum way in the project site, you should work productively in the project site with less idle time and generate profit for us.

So the equipment should be able to recover all the cost which was invested for its purchase. So, all the costs associated with the machine should be recovered by using the machine productively and by generating the profit. So, now let us see how to plan this equipment

utilization process. So, this is more critical when the same equipment is needed by a number of activities in a project site.

So, in that case we have to plan it very rigorously very carefully. So that there is no idle time for the machine and whenever the resources are limited, there are more chances for the project to get delayed, because of the waiting time. So, we have to plan in such a manner that the project the completion time is not significantly delayed due to the limited availability of the resources. So for that we have to plan the equipment utilization accordingly. So now let us see how to plan it with the help of a utilization chart.

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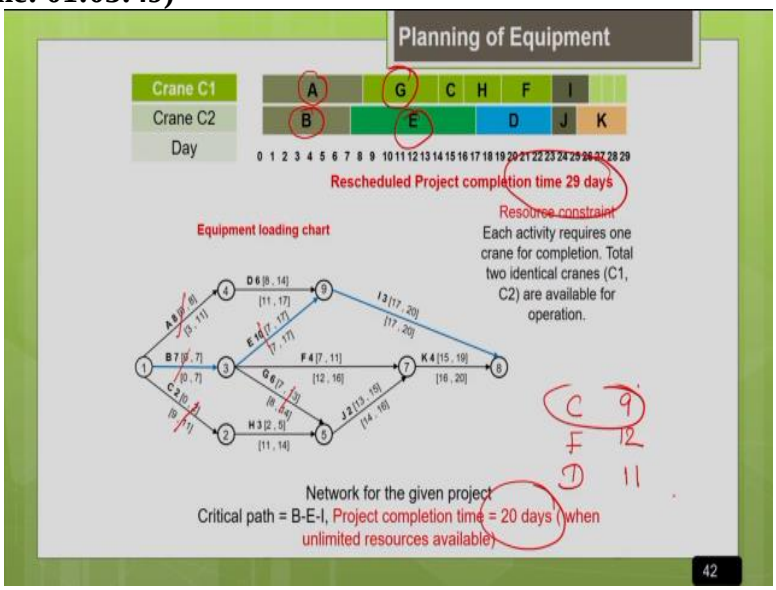

So in this picture, we can see a project network diagram I hope everyone knows about the project scheduling techniques like CPM and PERT. So in this course, I would not be able to dedicate a special time to discuss about the fundamentals of scheduling techniques like CPM, PERT, how to draw the network diagram, all these things I would not be able to discuss in this course, because it is not a part of the scope of this syllabus.

So I will just directly move on to the resource constraints scheduling how to plan the equipment utilization in this particular lecture. If you do not have the information or if you do not have the knowledge on how to do the project scheduling using CPM and PERT, I advise you that you should prefer some textbook on planning scheduling and control projects you will get the necessary information.

So, this slide shows the project network diagram of a particular project with activities from A to K. So, the activity duration is represented here as you can see A refers to the activity and 8 refers to the activity duration. So, above the arrow, you can see the numbers are indicating the earliest start time earliest finish time and below the arrow the numbers are indicating the latest start time and later finish time of the particular activity.

So, earliest start time is how early an activity can be started. And later start time is how delayed an activity can be started without affecting the project completion time. So, that means this particular activity A it start can be delayed by 3 days, but this one affect the project completion time. So this has a float of 3 ways. So, how much delay an activity you can accommodate without affecting the project completion time that is called as a float of the activity.

So, this particular activity A has a float of 3 days, that means the difference between the latest start time and the earlier start time is the total float of the particular activity. Similarly, you can see the earliest start time earliest finish times indicated for all the activities. So, now, let us see how the resource allocation has to be done for this particular project. So, for this particular project, first the network diagram is drawn, I mean, the scheduling is done assuming that resources are unlimited.

But everyone knows this cannot be real case in every project site there will be a constraint of resource, resources are never unlimited. So, there will be always a limitation for the resource. So, first it is drawn assuming that it is unlimited. And now the project completion time you can see it is 20 days. So, this project is getting completed in 20 days, if you assume there is no constraint on resources, resources are unlimited.

So, the critical part of this project is B, E and I, the critical path is nothing but the longest path in a particular project which decides the project completion time. So, for this project, that the critical path is B, E, I and its duration is 20 days. Now, for this project, apply the resource constraint. So, what is the resource constraint? So, for this project, for every activity, we need the crane for the completion of the activity, but the actual availability of the crane is there are only 2 cranes available with us, that is a resource constraint.

So, there are 2 cranes, each activity requires 1 crane for the completion, but in our project site, we have only 2 cranes available C 1 and C 2. So, now, how to allocate these 2 cranes for this

particular project, making sure that the idle time for the crane should be less as well as the project completion time should not be significantly delayed, because of this resource constraint, definitely, there will be some delay, but the delay should not be very significant, that we have to take care.

So how to allocate the resources on what criteria we are going to allocate the resources. So, we will go by the simple approach, which is commonly followed in many construction project sites that is least total float approach. So, least total float approach is a common approach followed. So, we are trying to identify the activities which are more critical. So, whichever activities have least total float, those activities are more critical, I mean, as I told you, the activities which have 0 float, they are called as critical.

So the activities which have less float, they are close to critical. So generally, first we have to allocate the resources to those activities which are critical that is whichever have 0 float, then that is least so, allocate the resources to those activities, which have least float then allocate the resources to those activities, which have second least float. So, we are allocating resources in the order of criticality of the activities, instead of float, I can also go by the least latest start time.

So, both are going to give you the same result only it is more convenient to use least latest start time approach. Now, let us start with the allocation, at the start of this project, you can see that there are 3 activities. So, you have this activity A, B, and C. So, there are 3 activities, which are the starting activities, beginning activities, and you can see that all the 3 activities require the crane, but you have only 2 cranes with you.

So now on what basis we can allocate the resource to these activities. So based on whichever activity is more critical, we have to allocate the crane to the particular activity. So this activity has the least float, we have to allocate. So, it means which activity has the least latest start time, we have to allocate the crane first. So, let us see for activity A, activity B and activity C. So, let us see the latest start time. So, activity A, the latest start time is 3, activity B the latest start time is 0, it is a critical activity.

So, activity C the latest start time is 9 so, 3, 0 and 9. So, whichever activity is having the least latest start time we have to allocate first. So, we are going to allocate a crane first to activity B,

we have 2 cranes. So, now, we can allocate the next crane to the second least latest start time so, second least latest start time is your activity A. So, in the beginning you can see the crane C 1 is allocated to A and the crane C 2 is allocated to B.

So, as of now I do not have a crane to allocate to C, I mean the activity C is waiting for the allocation of the crane. So, now, let us see the next allocation now activity B is getting completed in 7 days. So, you can see the duration of activity B is 7 days it is getting completed in the 7 days so, after this after 7 days, the crane C 2 is available for allocation now we have to allocate the crane C 2 to the next activity.

So, now see which are all the next eligible activities for allocation, so, which are all the next eligible activities for allocation? So, generally the activities for which all the preceding activities are completed then the succeeding activities become eligible for the allocation. So, after B since B is completed the eligible activities for allocation of E, F and G now after B so, what are all the eligible activities for allocation E, F, G as well as C because C is also not completed now so, C is also now eligible for the allocation.

So, now, after the completion of B which are all the eligible activities we can see E, F, G and C the latest start time is for E is you can see latest start time is 7 and for F latest start time is 12 and G latest start time is 8 and C latest start time is 9 now for whichever activity which is having minimum latest start time that is more critical we are going to assign now the crane will be allocated to E. So, after B you can see the crane is allocated to E. Now you can see the activity A is completed after 8 days.

So, now the crane C 1 is ready for the next allocation. So, now after A which one to allocate we have to see now. So, now let us mark which are all the activities completed A is completed, B is completed E is completed. So, now after A now we are going to see the allocation. So, which are all eligible after A obviously your D is eligible for allocation then so, this is already waiting, F is waiting, ready for allocation G is ready for allocation C is also waiting for the allocation.

So, let us see D, F, G and C are ready for allocation what is the latest start time let us see for D it is 11 then for F it is 12 and G it is 8 and C it is 9. Now look for activity which is having least latest start time it will be G. So, you can see after E, G gets allocation because it is more critical.

Similarly, after completion of G, G is getting completed first because the duration of G is only 6 days. Now, after G which are all the eligible activities you can see.

So, now, after G which are all the eligible activities, we have to see let us mark the activities which are completed A is completed so, B is completed your G is completed and E is completed. So, now, after G which is eligible, you can see that and already C is waiting F is also waiting, D is also waiting. So, now compare the latest start time C the latest start time is 9 and F the latest start time is 12 and D the latest start time is 11. So, the minimum you can see now it is for C so now do the allocation for C.

So on a similar basis you are going to do the allocation for all the activities based on whichever is critical. Suppose if there is a tie in the latest start time, then you have to go for the activity whichever has the minimum duration, why we go for minimum duration means, because, when the activity duration is minimum, the other activity waiting time will be less, because the usage of crane will be completed fast and the crane will be easily released to the next activity.

So, the waiting time of the other activities can be reduced when you go for the allocation of shorter duration activities. So, this is the basis on which the allocation is being done based upon the least latest start time or least total float approach. So, this is called the equipment loading chart. So, by looking at this equipment loading chart, you can see that the equipment is utilized in a very effective way there is no idle time for the machine.

So, now, you can see that reschedule because of rescheduling of activities, the revised project completion time is 29 days. So, the earlier we thought considering the resource constraint, the project completion time was 20 days, now, it is 29 days. So, whenever there is a resource constraint basically there will be a delay in the project completion, but we should try our level best to make the allocation to the critical activities first, so, that the project delay is not very much significant.

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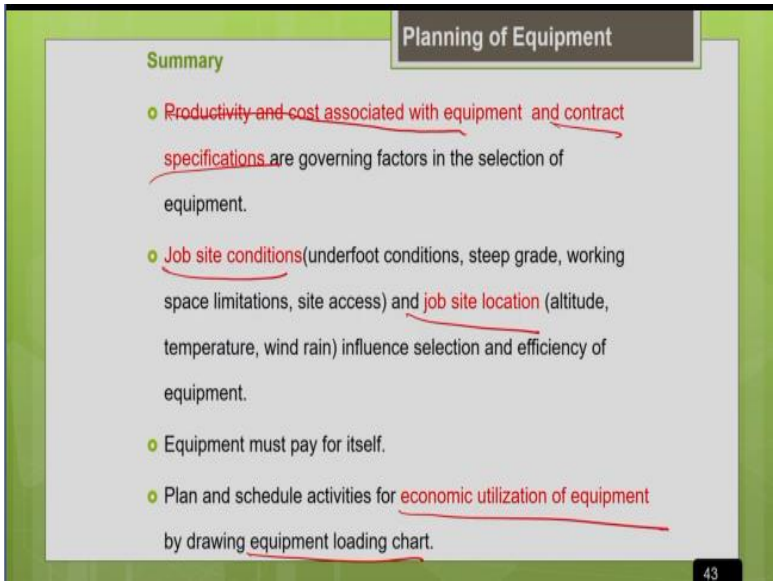

So, with this we are coming towards the end of this lecture, let me summarize whatever we discussed in this first lecture on planning of equipment. So, we discussed about the different equipment selection factors, and we found the productivity and the cost associated with the machine and the contract specifications are the important guidelines in the selection of the machine.

So, apart from that, your job site conditions or the job site location also will influence the selection of the machine to a greater extent. So, after selecting the machine after purchasing the machine, we have to plan for its economic utilization of the equipment that by discussing about resource constraint sharing and how to use the equipment loading chart for the economic utilization of equipment also we have discussed.

So, with this I have come to the end of the planning of equipment and as I mentioned in the beginning, the replacement analysis of the equipment will be discussed in the upcoming lectures. There is a separate lecture dedicated for the replacement analysis of the old machine with the new machine. So, in that particular lecture, we will discuss that particular topic.

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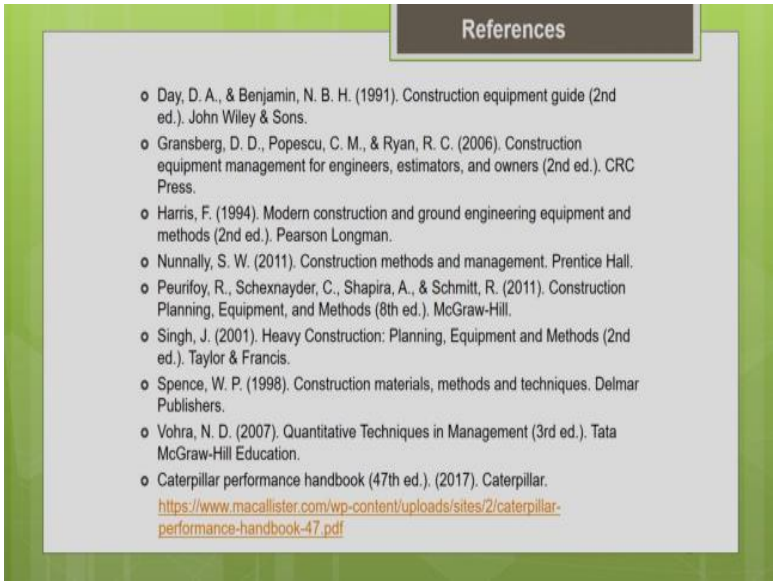

So, these are the reference textbooks. So, I advise you that you should refer some of these textbooks so that it will be easier for the course preparation. Thank you.