Construction Methods and Equipment Management
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Lecture-12
Earth Moving Equipment-Scrapers (Part-2)

Hello everyone, I welcome you all to the lecture 12 of this course. In this lecture, we are going to continue our discussion on the scrapers.

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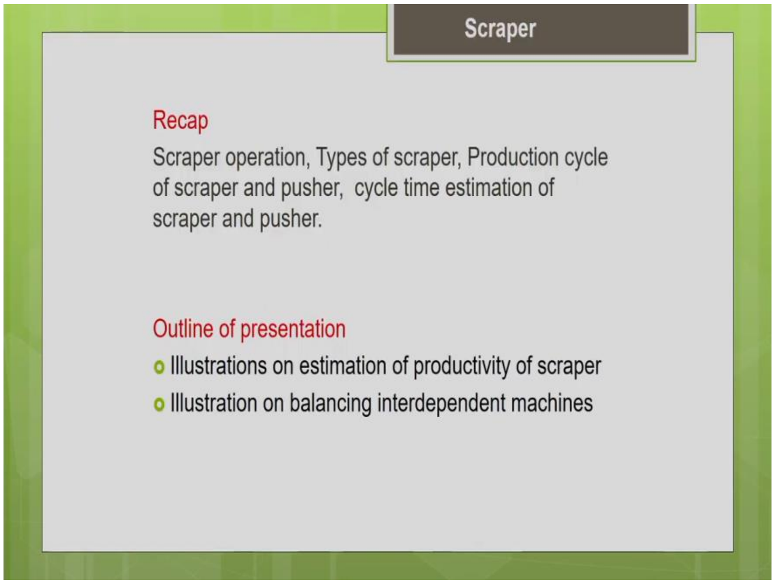

So, in the previous lecture, we have discussed about the operation of the scraper, types of the scraper and we also discussed about what are all components of the production cycle of the scraper and the pusher and how to estimate the cycle time of the scraper and the pusher. So, in this lecture, we are going to discuss or we are going workout some problems on the estimation of the productivity of the scraper. And we will also work out some problems on balancing the number of scrapers and the pushers which are the interdependent machine.

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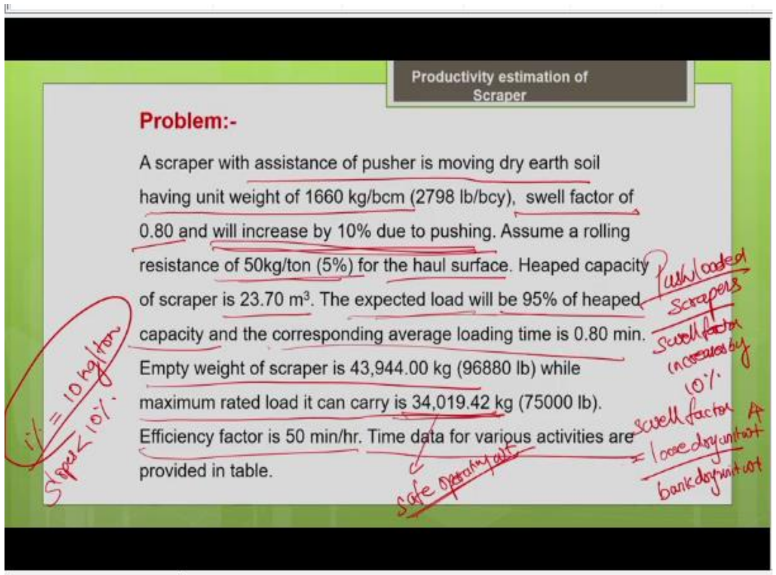

So, now, let us work on the first problem on productivity estimation of the scraper. So, a scraper with the assistance of the pusher is moving the dry earth soil having unit weight of 1660 kg per bank meter cube. So, you can see that this is a conventional pusher loaded scraper, here we are moving the material which is dry earth soil, its unit weight is given 1660 kg per bank meter cube.

So, the volume is given in volumetric measures is a bank state. So, that you have to clearly note it and the swell factor has given as 0.80. So, with the help of the swell factor you can do the conversion like from loose volume, you can convert it into bank volume or vice versa and you should know that this swell factor will increase by 10 % due to pushing. Why is it particularly for the push loaded scrapers?

Your swell factor increases by 10 % due to pushing. So, basically you know that when the pusher is pushing the scraper. It offers more additional pressure to push more material into the bowl. So, because of the additional pressure what is happening more and more material gets compacted inside the scraper bowl. So, due to the compaction of the material inside the bowl, you can see that the unit weight of the material inside the bowl will increase.

So, that results in increase of your swell factor. So, hope you remember what is swell factor? We have defined what is swell factor in early lecture, it is a ratio of loose dry unit weight of the material by bank dry unit weight of the material. So, particularly for the push loaded scrapers your swell factor, the unit weight will increase by 10%, because of the additional pressure which we received from the pusher to the material inside the bowl.

So, the material gets more compacted inside the bowl and because of that the swell factor will increase by 10%. So, this we have to always remember. So, even though the value is not given in the question, you should know that for push loaded scrapers by default swell factor will increase by 10%. Now, assume the rolling resistance of 50 kg per ton for this particular haul route the rolling resistance is 50 kg per ton.

So, if you want to convert it into equivalent gradient, you know that for 1% is a gradient equal to 10 kg per ton. So, this is a conversion factor which we discussed earlier, and this is valid for slopes less than 10%, we can use this. So, 50 kg per ton it is going to be 5%. Heaped capacity the scraper is given as 23.70 meter cube. They expect the load will be 95% of the heaped capacity. So, that means as we discussed earlier, we are not going to load the scraper to its fullest capacity.

If we load it to the fullest capacity, it will result in because of law of diminishing returns which we discussed earlier, it will result in decrease in loading rate after a particular time. So, that is why your loading times will increase a lot. So, the optimum loading time we have to follow for loading which we can derive from the equipment to manufacturer. So, here the expected load capacity is given to be 95% of heaped capacity.

That means we are going to load the scraper only to 95% of the heaped capacity. We are not going to load it to the fullest and the corresponding average loading time is 0.8 minutes. The empty weight of the scraper is given in kg. The maximum rated load it can carry is 34,019.42 kg. That means, this is the safe operating weight of the machine. For every machine, the safe operating weight is given by the manufacturer.

We are not supposed to load the machine beyond the safe operating weight. So, that will affect the structural frame of the machine, it will abuse the machine. If you are going to load it beyond the safe operating weight, it will affect the safety of the machine. So, we have to check whether your load or material within your bowl is going to be within this safe operating weight. That is a very important check we have to do, because the material density will vary from type to type.

So, we have to carefully check for the given material, what is that material weight. So, whether it is within the safe operating weight, we have to check. The efficiency factor has given as 50 minutes per hour the job efficiency. So, your machine is working for 50 minutes in an hour and the time data for various activities are provided to the table which we see in the upcoming slide.

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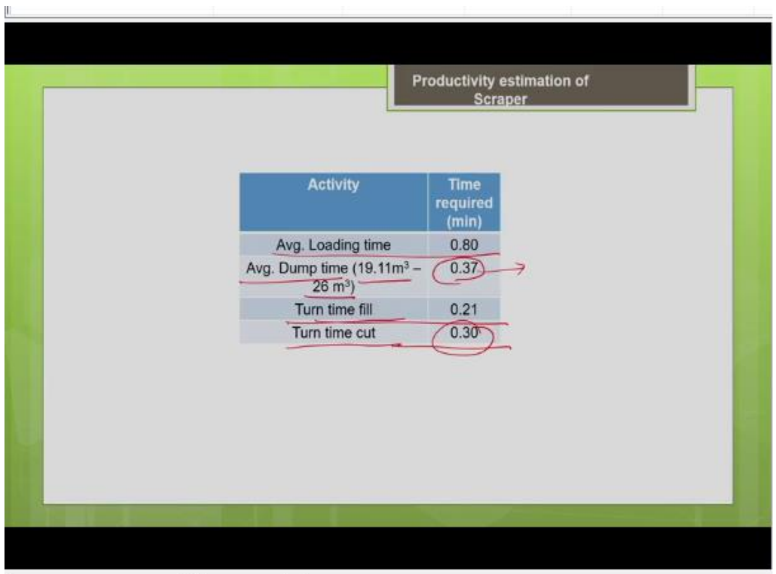

So, we can see it here, the average loading time is given by the manufacturers is 0.80 minute. Hope you remember it is given as 0.80 minute. Average dumping time, you can get it from the manufacturer it is available in the literature also. So, I have taken it from the literature. So, for 19.11 meter cube to 26 meter cube capacity scraper the value of dump time is given as 0.37 minute. As I told you, your dump time is going to depend upon your capacity of your scraper as well as it will depend upon your site constraints the congestion at your site and also depends upon the type of material it is going to handle.

So, you can take it from the manufacturer, the value from any literature. The turn time fill the average value is given as 0.1 minute and turn in time in the cut area is given as 0.30 minute. So, in the cut area it is slightly higher when compared to fill area, we have discussed the reason earlier.

So, these are the fixed time values, which are provided to us in the literature of equipment handbook.

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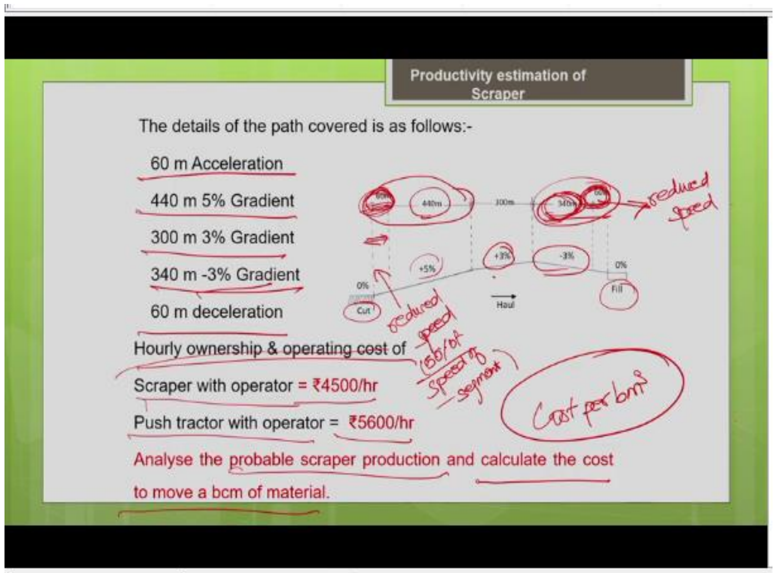

The other input data given is about the path about the haul route, about the haul distance and the resistance encountered in the haul route. So, we can see this is a pictorial representation of the haul route. You have the cutting area, you have the fill area, this is your haul route. So, you can see that for the first initial 500 meters, it is upslope, you have a gradient of + 5%.

Then you have 300 meter, you have a gradient of + 3%m then towards the end you have a distance of 400 meter with a down slope of - 3%. So, since different sections in your haul route have different resistances, particularly the gradients. So, we have to do the estimation section-wise or segment-wise. So, that is the reason we have split the haul route into different sections. So, another important thing you have to note it here is the first 500 meter, I have demarcated 60 meters separately.

This is because when your machine starts, so, when you are accelerating, you need some time for accelerating. So, immediately you cannot attain your desired speed, you need some time for accelerating and to reach the particular desired speed. That 60 meter is for acceleration. So, this initial 60 meter, it is going to be at reduced speed only, the initial phase will be in reduced speed. So, you can take it as approximately 50% of speed of this particular segment.

You can take this speed of 60 meter as 50% of the speed of 440 meter. So, initially you need some time for accelerating. So, that particular distance is 60 meter and these 60 meters this speed will be at reduced speed and we have taken it as 50%. And similarly, towards the end also you can see that out of 400 meter, the last 60 meter you have to slow down your machine. So, the time is needed for slowing down or decelerating.

So, that distance is 60 meter and this distance 60 meter will be also at reduced speed. So, this we can take it as 50% of the speed of the segment 340 meter. So, let me summarize what is given in this question the initial 60 meter distance is for accelerating then 440 meter, you have the 5% gradient, 300 meter you have 3% gradient, 340 meter it is your down slope - 3% gradient.

And the last 60 meter is for reducing your speed deceleration. So, the detail about your haul route is given distance as well as the gradient percentage and you know the rolling resistance. Rolling resistance is already given to you is given here. Assume we are rolling resistance 50 kg per ton 5% is for the haul surface. So, the rolling resistance is uniform throughout only the gradient is varying in the haul route that you have to note it.

Then the hourly ownership and the operating costs of the machine it is given directly to you, you know, we will have to estimate the ownership costs and operating costs. So, we are not going to estimate the cost again it is given as the input data. The scraper with the operator cost is rupees 4500 per hour and for the push tractor with the operator the cost is given us rupees 5600 per hour. Now we are going to analyze and find the probable scraper production and also find the cost to move a bank meter cube of material. So, you have to find the unit cost of production cost per bank meter cube, you need to find the unit cost of earth moving operation.

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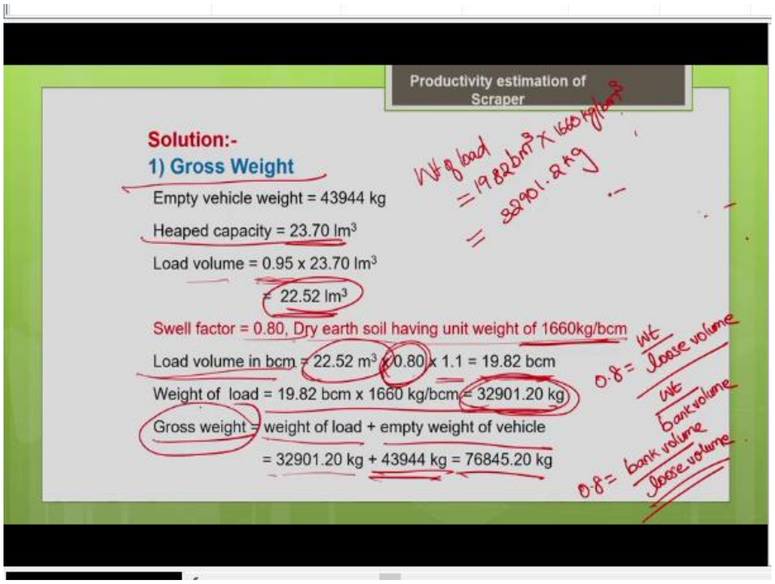

So, let us see how to proceed with this problem. So, the first thing you have to estimate is your gross weight of the machine. So, your gross weight of the machine is nothing but your empty weight plus the weight of the load in the machine, weight of the load in this scraper bowl. So, this is your gross weight the empty weight is given by the manufacturer. Now, I need to find what is the weight of the load in the machine?

But I know what is the volume of your heaped volume of volume of your heaped capacity of your scraper? The Heaped capacity is 23.7 loose meter cube the maximum heaped capacity of the bowl of the scraper when you heap it at a particular angle of repose; it is going to be 23.7 loose meter cube. Now what is the load volume? You need to find it. So, we are not going to load it to the maximum capacity as given by the equipment manufacturer, I will be loading to 95% of the heaped capacity.

So, your load volume is nothing but so how much I am going to load it 95%, 0.95 of your heap capacity. Your heaped capacity is 23.7 loose meter cube. So, that gives me the value as 22.52 loose meter cube, this is your load volume in loose meter cube. So, hope you remember here we have to estimate everything in bank meter cube. Your unit cost of production we have to estimate in cost per bank meter cube.

So, let me convert the loose meter cube into bank meter cube. So, how to convert? For that we need the help of this swell factor. The swell factor is given to you in the question for this particular material for this dry earth. So, the swell factor is given as 0.80. Swell factor is nothing but loose dry unit weight divided by bank dry unit weight. So, now, let me convert it into volume I need it in volume.

Weight divided by loose volume divided by the weight by bank volume. So, 0.8 equal to bank volume by loose volume. So, now, you can find your bank volume. Bank volume equal 0.8 into loose volume. So, load volume in bank cubic meters equal to your loose volume is 22.52 loose meter cube into the swell factor is 0.8. So, now, you have to increase the swell factor by 10% as we discussed earlier, because it is push a loaded scraper because of the additional compaction effect, in the effect on the material inside the bowl your unit weight will increase.

So, you have to increase the swell factor by 10%. So, that is why I have multiplied it by 1.1. So, now you get the answer is 19.82 bank cubic meter. The load volume in bank meter cube is 19.82. So, now let me estimate the weight of the load, weight of the load inside the bowl after I estimate the weight of load I have to check whether it is within the safe operating limits that is also important.

So, the weight of load inside the bowl you know the volume in bank meter cube 19.82 bank meter cube multiplied by the unit weight of the material is given in the question. The dry earth soil have a unit weight of 1660 kg per bank cubic meter is given in the question. You know the material property 1660 kg per bank meter cubed. So, when you multiply both you will get the weight of load as 32,901.2 kg.

So, that is what is derived here, weight of load is 32,901.2 kg. So, let me check what is the safe operating weight of the machine? As given in the question it will be given by the manufacturer. So, the maximum rated load it can carry is 34,019.42. So, this is within the safe operating weight of the machine. Now, let me find the gross weight of the machine. Gross weight is nothing but your weight of the load plus the empty weight of the vehicle.

So, weight of the load you have just determined 32,901.20 plus your empty weight of the vehicle is given in the question for the 43,944, when you add both, you will get the gross weight of the machine as 76,845.2 kg. So, this is how you have to determine the gross weight of the machine.

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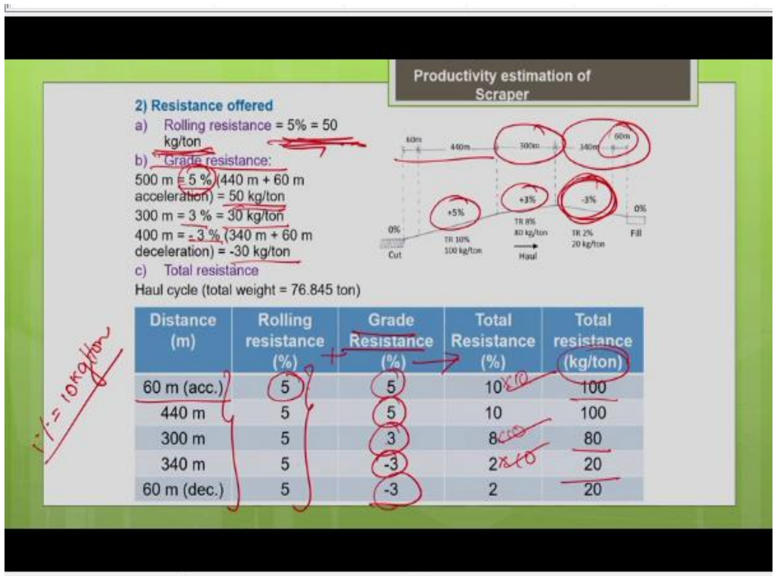

So, now the next step is we have to determine what are all the resistance in the haul route? The rolling resistance is uniform throughout the haul route. Is given in the question is 50 kg per ton or equivalent gradient as 5%. So, whatever way you express, you can take it accordingly. Then the grade resistance, the grade resistance is given for different sections, which we discussed just now. For the first 500 meters it is + 5%.

For the next 300 meter it is +3 % and for the next 400 meter, it is going to be the down slope - 3%. So, as you can also convert it into kg per ton you know the conversion factor 1% equal to 10 kg per ton. This is valid for slope less than 10%. So, you can convert the gradient also into kg per ton, 5% is equal to 50 kg per ton. 3% gradient is equal to 30 kg per ton and - 3% gradient is equal to - 30 kg per ton. Now, we need to find the total resistance.

So, let us prepare it in the form of table so, that it will be very convenient to analyze. So, follow this table formatting. So, we can see the different segments distances. So, for the first 60 meter, the rolling resistance is 5 you can see that for all the segments the rolling resistance is same it is

5% or 50 kg per ton. Next is grade resistance for the 60 meter it is + 5%. The next 440 meter it is + 5%, 300 meter it is + 3%.

Then the 340 meter you can see it is - 3% and the last 60 meters, you can see it is again 3%. You add both rolling resistance percent plus grade resistance, you add both you will get the total resistance in percentage 5 + 5 =10, 5 + 3 = 8, 5 - 3 = 2, so like that you add both. Now, you can also express in kg per ton. Just multiply it by 10, 10 into 10 =100 kg per ton, 8 into 10 = 80, 2 into 10 = 20. So, you can use either one of this, but I have expressed in both.

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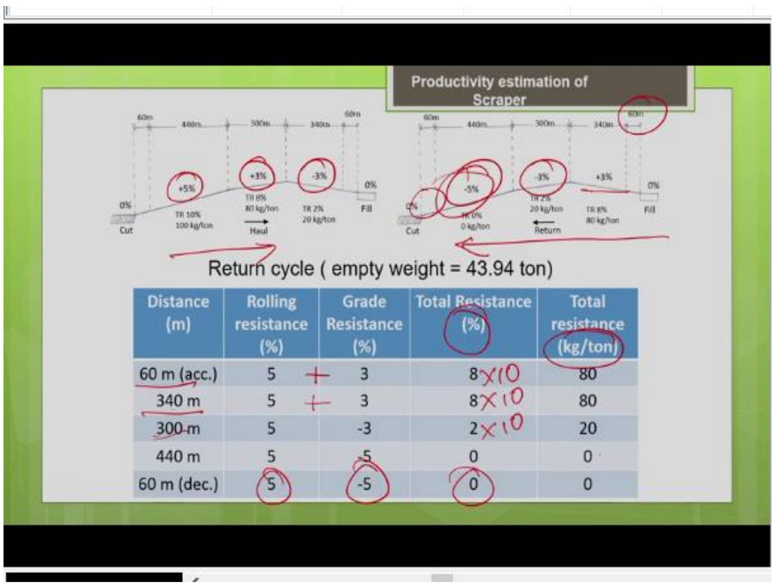

So, that was about the haul cycle. Now, it is about the return cycle. The return cycle you have to be very careful in analyzing the haul route. You know that now the machine is moving from this end to this end. So, whatever gradient we have discussed here in the haul travel, say here if it is + 5%, in your return travel it is going to be - 5%. Similarly, here it is + 3%. In return travel it is going to be - 3%. Here this is - 3% in return it is going to be + 3%. So, whatever it was upslope in your haul travel in a return travel it is going to be downslope. So, accordingly, you have to choose values and then estimate it correctly.

So, now, let us see for the first 60 meter here the first 60 meter. You can see the gradient is + 3%. As I mentioned earlier the rolling resistance is going to be same for the entire haul route. For the next 340 m obviously, it is same + 3%. Now, for the next 300 meter, you can see it is now down the slope. So, it is - 3%. For the 440 meter, it is again down the slope. So, it is - 5%. The last 60 meter distance where you reduce the speed. It is again - 5%.

Now, add both rolling and grade resistance. So, that you can get your total resistance percentage 5 + 3 = 8, 5 + 3 = 8, 5 - 3 = 2, 5 - 5 = 0, 5 - 5 = 0. You can also convert the resistance percentage into kg per ton multiplied by 10, 80 kg, 80 kg, 20 kg, 0 and 0. So, now, we have determined the total resistance in percentage as well as in kg per ton for the entire haul route as well as for the return route. So, in order to determine the speed of the machine, I need the help of the performance chart. So, now with the help of the performance chart, if you know the total resistance and if you know the gross weight of your machine you can calculate the speed of machine as we discussed earlier.

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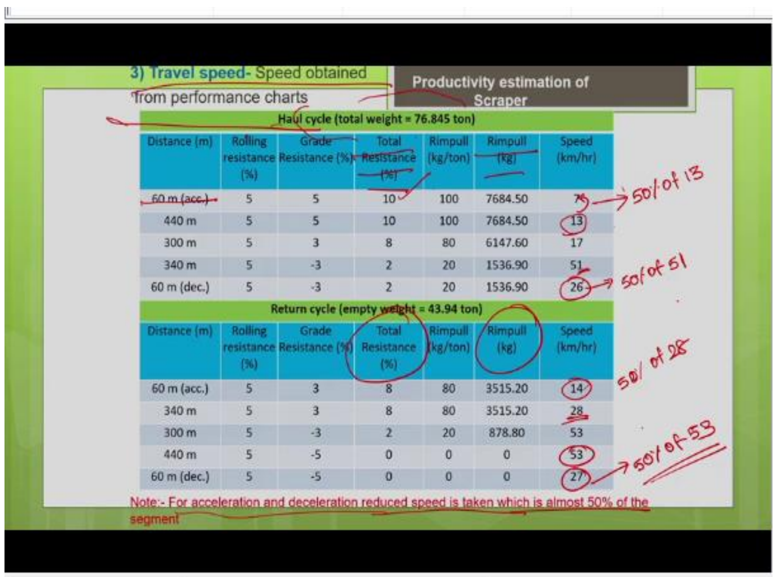

Haul cycle (total weight = 76.845 ton)						
Distance (m)	Rolling resistance (%)	Grade Resistance (%)	Total Resistance (%)	Rimpull (kg/ton)	Rimpull (kg)	Speed (km/hr)
60 m (acc.)	5	5	10	100	7684.50	7
440 m	5	5	10	100	7684.50	13
300 m	5	3	8	80	6147.60	17
340 m	5	-3	2	20	1536.90	51
60 m (dec.)	5	-3	2	20	1536.90	26

Return cycle (empty weight = 43.94 ton)						
Distance (m)	Rolling resistance (%)	Grade Resistance (%)	Total Resistance (%)	Rimpull (kg/ton)	Rimpull (kg)	Speed (km/hr)
60 m (acc.)	5	3	8	80	3515.20	14
340 m	5	3	8	80	3515.20	28
300 m	5	-3	2	20	878.80	53
440 m	5	-5	0	0	0	53
60 m (dec.)	5	-5	0	0	0	27

Now I need to determine the travel speed from the performance chart. The total weight of the machine is express in tons 1000 kg equal to 1 ton. Accordingly, we have to convert it into tons. So, during the haul cycle, it is a loaded condition 76.845 ton. During return cycle it is empty. So, the empty weight of the vehicle is 43.94 tons. So, you have already calculated your total resistance already in both percentage as well as kg per ton. We are already determined in the earlier slide.

Now, using the performance chart, hope you remember the performance chart either I can use the total resistance percentage or I can use the rimpull value. So, hope you remember in the left hand side, you have the performance chart, in the left hand side you have the rimpull and in the right hand side you have the total resistance in the percentage, in the x axis you have the speed. So, based upon your different gear curves, we have discussed this already we have to based upon your total resistance you have to find the speed of the machine from the performance chart.

So, this rimpull in kg see already we have determined earlier for kg per ton. So, according to the weight of machine, so here the gross weight of machine is 76.845 ton. So, multiply rimpull and kg per ton into the gross weight of the machine. You will get the total rimpull in kg. So, 100 into 76.845 gives you 7,684.5. Similarly, 80 into 76.845 gives you 6,147.6 kg. So, this 80 kg per ton is converted into 6,147.6.

Similarly, 20 kg per ton multiply with a gross weight of machine 76.845 it gives you 1,536.9 kg total rimpull in kg. So, you can do the conversion. So, use this total rimpull or total resistance either of these you can use and find the corresponding speed in the performance chart. So, I have assumed some approximate values. Actually, you are supposed to choose it look for the correct scraper model number.

Take the equipment handbook, in the equipment handbook, look for the particular model number you will have the performance chart for the model number, then from the performance chart, you know the total rimpull or corresponding speed you can find it or with the help of total resistance percentage corresponding speed you can find it. Similarly, for your return cycle, the rimpull weight is given kg per ton already we have determined, based upon the empty weight of machine 43.94 you find the total rimpull.

So, it is nothing but 43.94 multiplied by 80, 43.94 multiplied by 80 gives you 3515.2 kg, similarly, say here 20 kg per ton. So, 20 multiplied by the empty weight of the machine is 43.94 tons. So, that gives you the value is 878.8 kg, this is a total rimpull. So, you can use your either the total rimpull value or the total resistance percentage and find the speed. So, one thing you can note here is your return speed is higher when compared to the haul speed.

Because this is in loaded condition, return speed is in empty condition. So, the speed is obviously higher. So, another important thing you have to note it here is say the 60-meter initial segment for acceleration, I have taken it approximately as 50% of 13, it gives me the speed for the initial portion of the segment where you need some time for accelerating that portion will be at the reduced speed only.

Similarly, towards again the last 60 meters when you try to reduce the speed, so, that will be also you have to take it as 50% of the previous one, that is 51, 50 % is a 51 approximately 26. Similarly, for your return travel this is the initial segment take it as 50%, your 14 is nothing but 50% of your 28. Similarly, the last segment 27 you take it as 50% of your previous one 53. So, that will give you 27 approximately. So, for acceleration and deceleration reduce speed is taken which is almost 50% of the segment, we discuss the reason already earlier.

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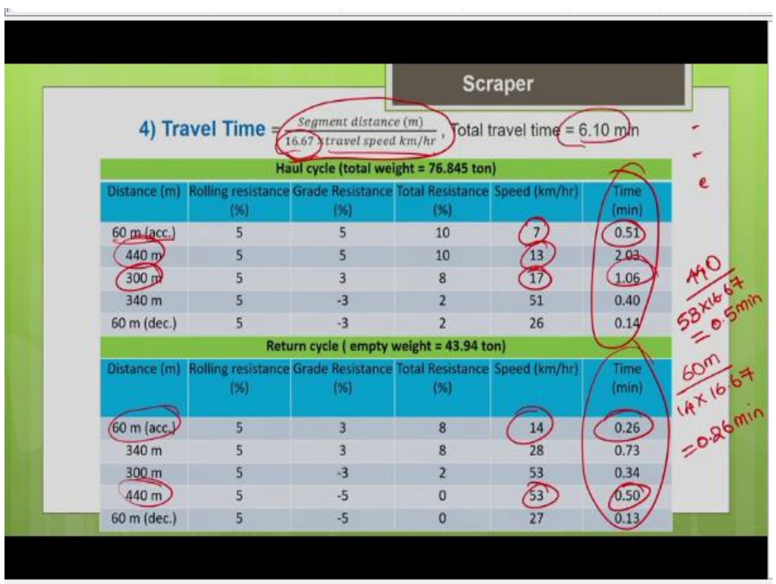

So, now, you need to calculate the travel time. So, we have calculated the speed. You know the speed for different segments. You know the haul distance for different segments. Now, you can calculate the travel time. So, time is nothing but your distance by speed, for every segment you are going to calculate it. Say for the first 60 meter, the speed is given in kilometers per hour 7 kilometer per hour. Haul distances is in meter.

So, let me convert it to a kilometer per hour into meter per minute, 1 kilometer per hour equal to 16.67 meter per minute the conversion factor. So, multiplied by 16.67. So, you will get the answer is 0.51 minute. Your travel time is segment distance divided by travel speed kilometer per hour into 16.67, that is your conversion factor. Similarly, do it for all the segments one by one.

Say for the next segment for 440 meters the distances is 440 divided by distance is 440 speed is 13, the conversion factor is 16.67. This gives me the answer is 2.03 minute. The next segment is 300 meter. The distance is 300, speed is 17, the conversion factor is 16.67 that gives you the answer is 1.06 minute. Similarly, you can do it for everything, the same way for the return time. So, return time you can see for the first segment it is 60 meter divided by the speed is 14 kilometer per hour into the conversion factor is 16.67 that gives you the time is 0.26 minutes.

Similarly, say 440 meters 440 divided by the speed is 53 the conversion factor is 16.67, you get the time as 0.5 minutes. So, add all the time for the haul route. Haul time as well as the return time. If you add everything you will get the total travel time is 6.1 minute.

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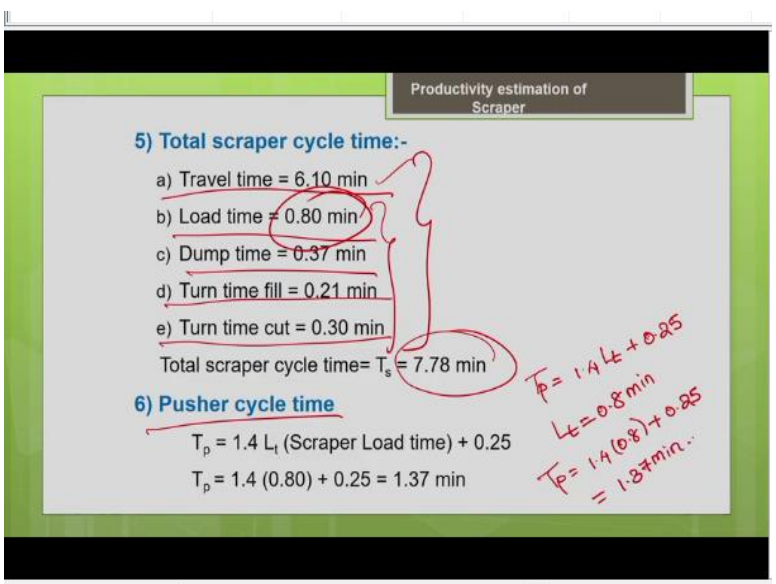

So, this is how you have to determine the total travel time. Let me know the summary is whatever we have discussed so far. The travel time we have determined is 6.1 minute, hope you remember the travel time is 6.1 minute. Loading time is 0.8 minute. Dump time 0.37. Turn time 0.21. Turning time in cut area 0.3 minute. So, these are only a fixed time. This is your variable time and add everything you will get the total scraper cycle time is 7.78 minutes.

You have to add everything. Now find the pusher cycle time. So, pusher cycle time I am going to follow backtrack loading method. So, let me use a caterpillar formula, that is nothing but

$$T_P = 1.4\ L_t + 0.25,$$

your loading time you know already it is 0.8 minute. So, your pusher cycle time is 1.4 into 0.8 + 0.25. So, that gives you the answer is 1.37 minutes. So, we have estimated the scraper cycle time and the pusher cycle time.

The next thing is we have to balance the number of scrapers and the pushers. Like I say as I mentioned earlier, we need to balance the interdependent machines so that one need not wait for the other. So, by this we can reduce the waiting time of the machine. So, that way you can reduce the cycle time of the production and you can increase the productivity and reduce the production cost. So that is why we have to go for balance number of scrapers and pusher so that we can minimize the waiting time of the machines.

So as we discussed earlier, you know that the pusher cycle time it is going to be relatively smaller than the scraper cycle time. This is because your pusher will be helping the scraper only during the loading phase. Once a scraper bowl is completely filled so now the scraper will get detached from the pusher and it can haul the material on its own. So, scraper needs the assistance of the pusher only during its loading phase that is why one pusher can serve even up to 4 to 5 scraper.

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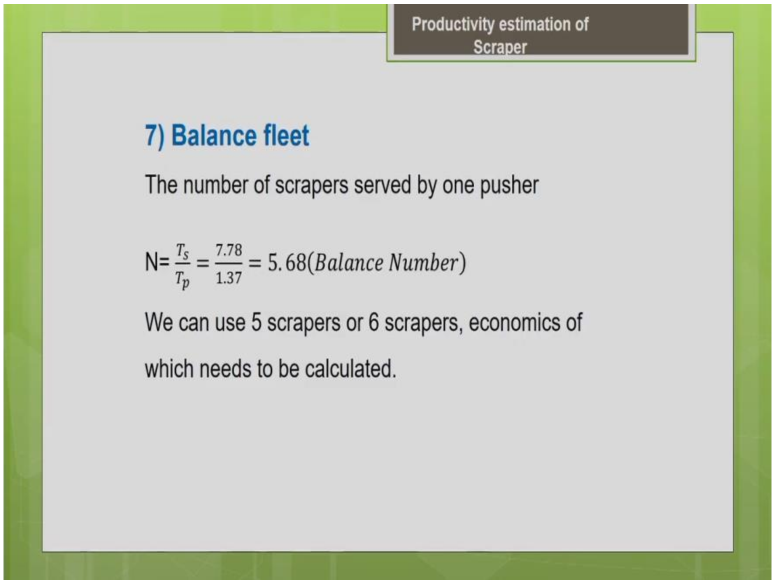

Now let us see the balanced number of scrapers which are served by one pusher. So, that is equal to n is nothing but number of scrapers served by one pusher. It is equal to cycle time of the scraper by cycle time of the pusher. So, here we have estimated the cycle time of the scraper as 7.78 minute. And the pusher cycle time is 1.37 minutes. So, it is 7.78 divided by 1.37 gives you the value as 5.68.

$$\mathrm{N} = \frac{T_s}{T_p} = \frac{7.78}{1.37} = 5.\ 68(Balance\ Number)$$

So, now the balanced number is 5.68. This balanced number indicates the level at which the production level of both the machine are same scraper and the pusher. So, it means both are working at a maximum production level, but it is not possible for us to go by 5.68 per pusher. So, we have to round it. Since we get the decimal number, we have to either round it to the lower number or rounded to the higher number. Either I can go for 5 or I can go for 6.

So, we have to work out the economics of both the cases. If I go for 5 scrapers what will be the associated productivity and production cost? If I go for 6 scrapers what will be the production and unit production cost? We have to work out the economics and take a call whether to go for 5 scrapers or 6 scrapers accordingly.

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