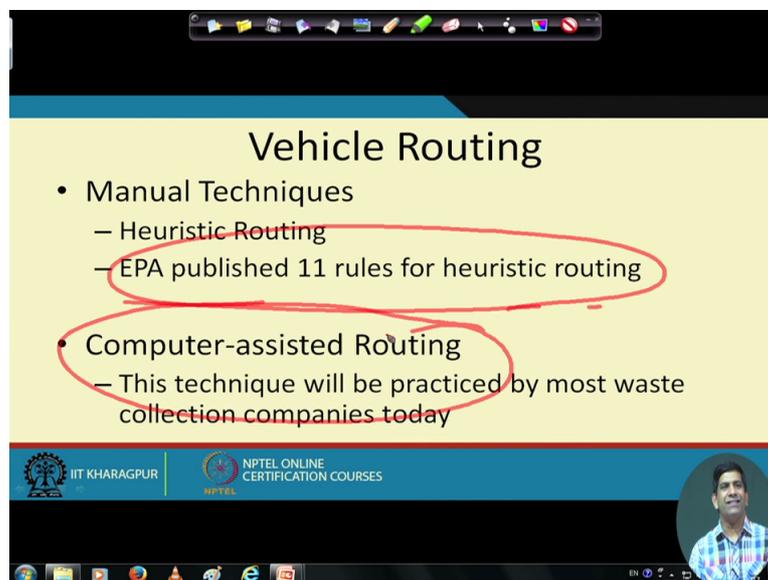


Course on Integrated Waste Management for a Smart City
Professor Brajesh Kumar Dubey
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Module 5
Lecture No 22
Waste Collection and Transport (Contd.)

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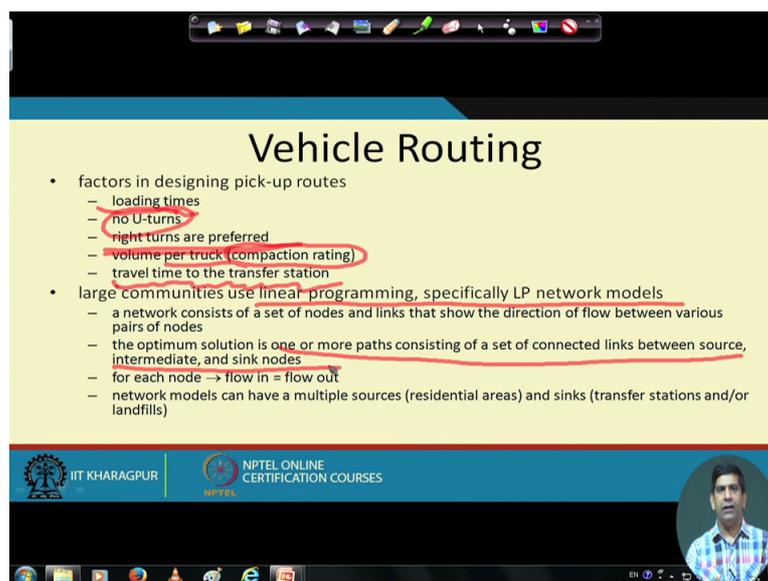
Okay so welcome back this is the second model for week 5, so will continue our discussion of the collection system for municipal solid waste, so as if you remember we were talking about in terms of the trucks how the waste would be collected then one of the important point is how to route this truck because this vehicle routing is one of a very critical component in terms of waste collection because if we can do the routing properly with if we can reduce as I

said number of trucks required, so if we can optimize resources that always helps in terms of the finance, in terms of the budget.

So there are in terms of the vehicle routing there is manual way of doing it there is a heuristic routing, heuristic routing means there is some guidelines EPA published 11 rules for heuristic routing like how we should do the routing and then how we should move the truck and all and we will go that. It is a bit lots of text there but I will try to highlight some of the important stuff but other important what has happened over last few decades is that people have taken this information from this particular website and from the particular like a guideline and then have developed a computer software.

So there is a computer-assisted routing, so nowadays nobody actually does a manual outing, so there is a computer-assisted software which takes into account all the 11 rules which will talk about in a minute and also some of this operational research linear programming and all those concepts are incorporated here, to come up with better vehicle routing and again the concept here is same as what if you get if you are working for Amazon or Flipkart or Snapdeal and if they are trying to do the logistic in terms of transportation the basic concepts are the same because we trying to move a particular resource whether you call it a waste or a product from place A to place B and how to do it in a more efficient way, so that is the overall goal in terms of the vehicle routing.

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Vehicle Routing

- factors in designing pick-up routes
 - loading times
 - no U-turns
 - right turns are preferred
 - volume per truck (compaction rating)
 - travel time to the transfer station
- large communities use linear programming, specifically LP network models
 - a network consists of a set of nodes and links that show the direction of flow between various pairs of nodes
 - the optimum solution is one or more paths consisting of a set of connected links between source, intermediate, and sink nodes
 - for each node \rightarrow flow in = flow out
 - network models can have a multiple sources (residential areas) and sinks (transfer stations and/or landfills)

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So in terms of vehicle outing lots of factors in the design like you need to look at loading time because every house you go to every apartment complex you go to you have to load this

garbage so you have to look at one of the factors that you need to be careful about the loading time that you taking at each one of the place. Then you avoid taking U-turns because when you are trying to take U-turns that is actually a problematic in terms of taking too much of U-turns, you are basically wasting time, you are not being efficient so you try to avoid taking U-turn.

This document this EPA as you know USEPA United States Environmental Protection Agency. So since they travel they drive on the other side of the road so they are on the right-hand side of the road, so they can take the right turn is much easily like we can do left turn here, so right turns are preferred, so in our case it is the left turn which is preferred. So there it says right turns are preferred because this is again the information is directly from the EPA website document.

So I had in change it because it should be as it is but in Indian context we will focus on the left turn will not focus on right turn because that is not the way we drive over here and how much waste can go in a truck what should be the compaction rating? Because trucks these days are coming with the self-compactor and what should be the compactor, if you compact too much that is also a problem if you remember if the waste is going to the waste to energy plant or waste is going to landfill if you have too much of compaction then you have to give compact while unloading the garbage at the disposal or the treatment site.

And then you should take into account the travel time to the transfer station if you have a transfer station, how much travel time it will take to get there? So large communities they use linear programming, they especially like linear programming network model so it is a network consist of a set of nodes then you have links showing the flow into the node and flow out of the node and then we try to come up with an optimum solution comes with one or more part consisting of set of connected links between source, intermediate and the sink nodes and for each node there is a flow in and flow out, so network model can have multiple sources and sinks for example residential areas, transfer stations, landfills and so again, but the nice network model and analyse model and come up with the solution for routing.

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Vehicle Routing

- factors to consider:
 - times to/from the first/last home
 - local routes need input from vehicle drivers (routing coefficients)
 - unloading time at transfer stations/landfill
- there is a need to consider all options
 - the local landfill, or transport to private landfill?
 - the decision variables are routing times through the network
 - the objective → minimize routing time
 - time = money
 - the constraints on the system are travel times along each route, capacities of each transfer station/landfill, conservation of material at nodes, ...
- as more information comes from operating the actual collection system, the process can be refined by trial and error, or through the use of the linear programming model

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So some of this other data that we need to take about that in terms of routing time, (())(5:40) time, to and from the first and last home, so for example if the collection system starts at the point like if you the waste collection may start from the first home or the first apartment complex that truck is going to but before it does that the time taken from the garage the first home and similarly with the time taken from the last home when the garbage truck is full the transfer station to the waste-to-energy plant or to the landfill pending upon the scenario.

So both these terms are also part of the route, so we need to take that into consideration and we should try to minimize this, some of the things is in our control some may not be in our control depends on the location of the garage, location of the first houses. Based on the situation you can try to optimize these parameters as well. Then local route you need input from vehicle drivers, so vehicle drivers routing coefficients, so we have to will talk about the drought in coefficient, so for this routing coefficient you need the data, basically you need to know out the traffic behaves in that area at different time, different point of the day and that is how you decide you routing coefficient and we will talk about routing coefficient.

What I will do is after doing this particular theory part I will have a set of problems with you on this so far what we have done in terms of how to get the waste quantity, waste collection and collection system. So try to do some math and there we will talk about this routing coefficient, how we get all those numbers? So will do some math associated with that and then there is unloading time at the translation or other landfill, so the truck will go to the transfer station or landfill and then it has to unload the garbage over there so that unloading time needs to be taken into consideration as well.

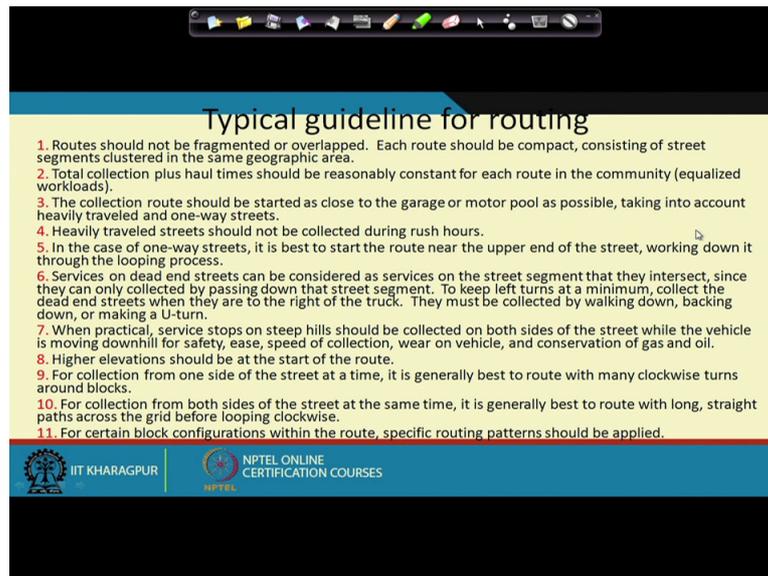
So all those things seems quite trivial they need to be accounted for because if you miss something your optimization will fail and you will have a wrong result and then you there is a need to consider all options especially if you are trying to develop a new integrated waste management plan for the city, we should have and I think I said that earlier as well, we should keep all options on the table many a times even when we say the word landfill, as a people get oh no no no we do not want in a landfill in India, landfill is so outdated.

Yeah to a certain extent I may agree but even in Western Europe and countries who are working on waste management for last 40 some years, they still have not been able to get rid of landfill, so landfill is a necessary evil, you can say that it is a necessity you can say it is an evil but same time it is a necessary evil, you have to live with it. So in terms of different options you can go for an option of landfill, it should be a government landfill to a private landfill, or compost plant, we can build a transfer station and will talk about that in a minute and so there are lots of decision variables can be there in terms of the routing time and objective is to minimise the routing time because time is time money.

So if you can minimise the routing time that really helps us in terms of minimizing the cost and that is important for any business like you do want to for the same performance why to pay more cost, so you should actually be less cost and this was the trying to achieve our there. So the constrain of the system are the travel time, we have look at the travel time along each route, capacity of transfer station, conservation of materials at the nodes. So those things are there and this is iterative process, so you design one time, you run this model, you let the trucks go and do the stuffs and then when the truck driver will give you some input back and how the truck worked, you get some input back from there then you go and refine it.

So as more information comes from operating the actual collection system, the process can be refined by trial and error, so the use of the linear programming model. So this is again those can be done, so this vehicle routing is very interesting stuff in terms of the waste management which could be of a good interest to anybody who is like who are interested in optimization operation research and those kind of work.

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Typical guideline for routing

1. Routes should not be fragmented or overlapped. Each route should be compact, consisting of street segments clustered in the same geographic area.
2. Total collection plus haul times should be reasonably constant for each route in the community (equalized workloads).
3. The collection route should be started as close to the garage or motor pool as possible, taking into account heavily traveled and one-way streets.
4. Heavily traveled streets should not be collected during rush hours.
5. In the case of one-way streets, it is best to start the route near the upper end of the street, working down it through the looping process.
6. Services on dead end streets can be considered as services on the street segment that they intersect, since they can only be collected by passing down that street segment. To keep left turns at a minimum, collect the dead end streets when they are to the right of the truck. They must be collected by walking down, backing down, or making a U-turn.
7. When practical, service stops on steep hills should be collected on both sides of the street while the vehicle is moving downhill for safety, ease, speed of collection, wear on vehicle, and conservation of gas and oil.
8. Higher elevations should be at the start of the route.
9. For collection from one side of the street at a time, it is generally best to route with many clockwise turns around blocks.
10. For collection from both sides of the street at the same time, it is generally best to route with long, straight paths across the grid before looping clockwise.
11. For certain block configurations within the route, specific routing patterns should be applied.

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These of the 11 guideline I will not bore you with reading each one of those because we just came from the US EPA document, so I will just highlight a few important stuff you can always read it, you will have the PDF of each slide available to you, so it the thing is that you should try to keep some of the key point is we should try to keep it compact you try to have that route in one particular geographical area at one time rather than having part of the route covering this part of the city. Then goes to the other part, then goes to the other part then you actually wasting time while moving the (11:15).

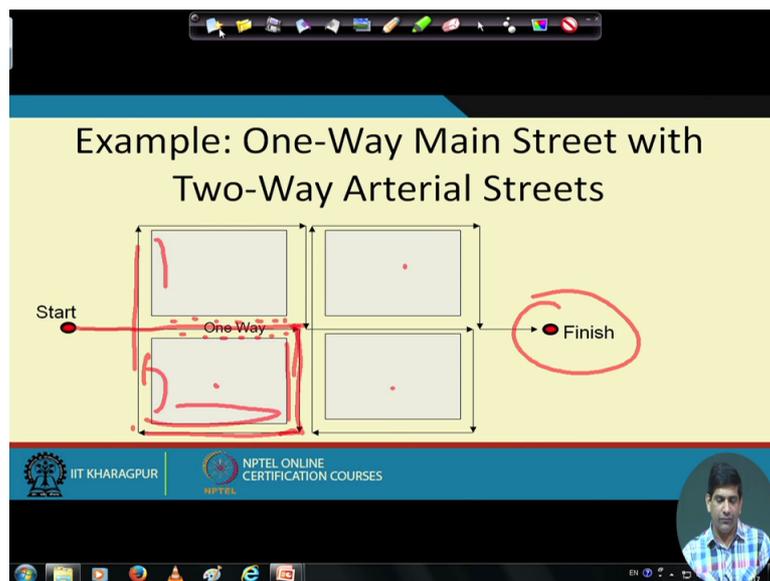
Just focus on one area and let the truck do over there the other truck can do over here so that is how we need to design it and total collection plus the halt time, halt time is the time taken from the garage to the first house and from the last house to the landfill or transfer station, so that time is the halt time and when you are collecting garbage at each of the houses is your collection time, so the total collection time plus the halt time, it is better to be equal among the different route.

Say city has a particular city as may be 20 routes going on for different areas of the city. All those 20 routes terms of the time try to keep it similar, so that it equalize workload. So that all the workload have similar work hours collection route should be started at close to the garage or the motor pool as possible (12:14). Heavily travel one (12:17), so heavily travels streets should not be collected during the rush hour, so you do not want to collect any garbage collection in the (12:27) of a school during the morning school hours, is it not? It will be kind of your wasting lot of gas and gasoline there itself.

So you do not want to do that because you know during the rush hour, during the school hours specially with a school starts and when the school ends, there will be lots of traffic in that area so it is better you avoid that time and you do the waste collection between while the school is running or may be too early in the morning or too late in the evening but that is up to you, you can design your system but and of course the people who will work on there.

So in case of one-way street you try to do it from the upper end of the street, service on the dead end, so there are different stuff there, higher elevation should be done with the (()) (13:13) and then you do a specific routing pattern this is again you can read through this is not much complex stuff to understand a just give you some guideline and as I said earlier most of these software they do take into account all these guidelines when they design those software.

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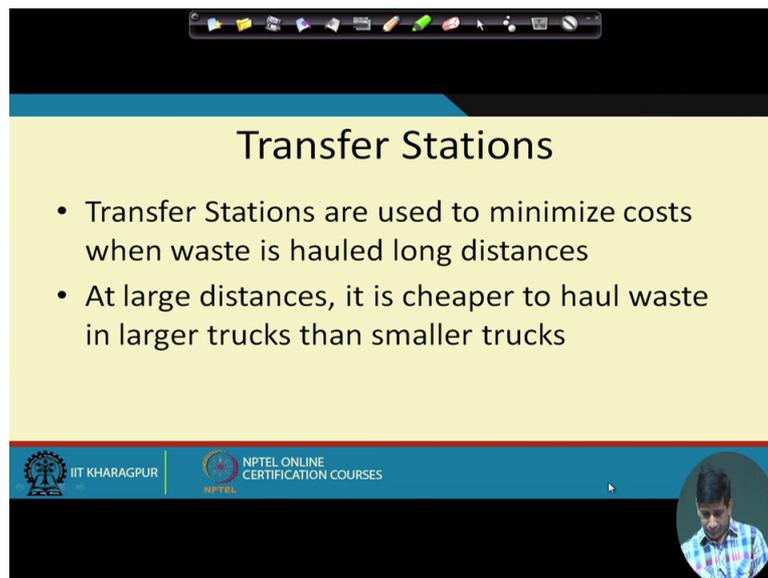
So let us look at this particular example in terms of very simple example in terms of the waste collection system, so if you have this as you can see on the screen if you have a one way main street with 2 way arterial street, so we have a one-way Main Street here that is our Main Street when there are and we have we like a two-way arterial street, so thing can go on both the sides here, so here again could be multiple solutions there is one solution where if you have to do this waste collection system you can start from there and then you can come here and since this example was from my teaching days in North America.

So actually again we have taken a right turn because right turn it is prefer to take right turn, so you come here, collect the garbage along this length of the house and from the other side

as well and then you take a right collect the garbage from you and then you go here, collect the garbage from this side and then you go back up and the collection on this and this and then you can kind of go back go back and forth and do the collection and this is your end finish point over here.

So this is one example and here we have we have tried to take into account all those 11 guidelines which was available from your CPA, so but you can still come up some other solution to that as well, so there is no just one route it could be multiple routes but this is one example where you can do the routing based on that, so this is just 4 blocks maybe around some 35 - 40 houses may be slightly more but this can be we can potentially do it by hand as well but if you think about a big city or other stuff you cannot do it by hand now, you need to rely on some computer software do that but you should understand what that computer software does so that you can make a good judgements in terms of route optimization.

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Transfer Stations

- Transfer Stations are used to minimize costs when waste is hauled long distances
- At large distances, it is cheaper to haul waste in larger trucks than smaller trucks

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And other thing is the use of the transfer station, transfer station is the place where we say if you are these days in India so after the Swachh Bharat mission or even before that, this is concept of regional landfills are coming up so for example Kharagpur town if when it goes for a engineered landfill it will not only if you implement this MSW management rule only we will have wet and dry separation.

Wet waste should go to a compost or anaerobic digester (16:22) and all those kinds of stuff, so dry waste after the recyclables are gone that it can go to a waste-to-energy plant or it can go to a landfill, the amount of dry waste coming from a town should not be that much

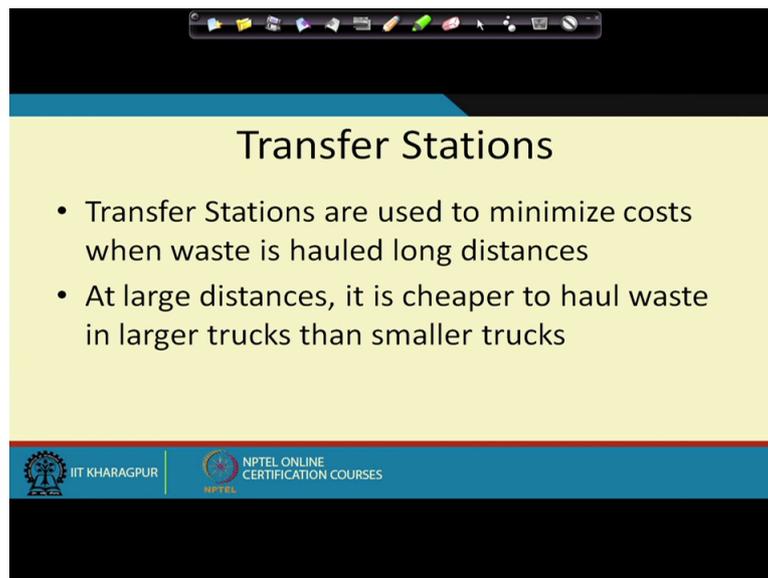
because we have already taken care of the food waste, we have already taken care of the recyclables.

So we may not have enough capacity coming from one particular town or one particular city, so the concept of this regional landfill which is there in many parts of the world also being kind of push forward in the Indian context, so these days with Swachh Bharat mission we were reviewing some we work with Bihar government on that and we (17:05) from them for Swachh Bharat mission like a solid waste management integrated solid waste management plant and their most of the places they were suggesting that they will try to have a transfer station.

So because what does that mean, there is a smaller truck same Kharagpur town, the smaller trucks which is going around the Kharagpur town collecting this garbage and bring it to a talking about non-recyclables, non-compostable one and bring it to a Central location on may be on the outskirts of the city on one side of the city and that location is your transfer station where there are smaller trucks brings the garbage from the town dump said there bigger trucks comes in and bigger trucks take this load and bigger truck carries it over the highway and to the regional landfill and the regional landfill is shared by several cities several town surrounded.

That is the concept is being developed or is being promoted as a part of new integrated waste management and framework including this Swachh Bharat mission, so we did reviewed and we saw at in many of the DPR are proposing that and actually government is encouraging that and I can understand because it makes sense. Rather than having small landfill you can have a bigger landfill you can have a good control over there you can have an engineered landfill and that is always better.

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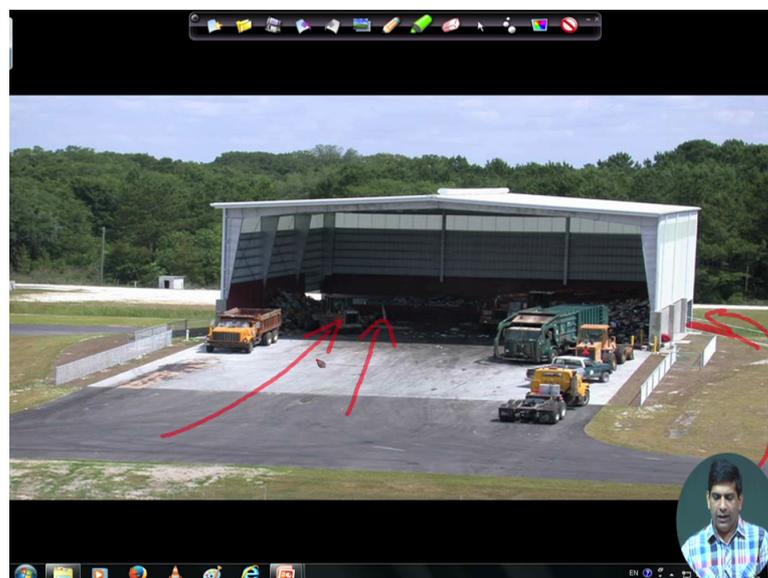
Transfer Stations

- Transfer Stations are used to minimize costs when waste is hauled long distances
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So transfer stations are used to minimise cost because for a than taking smaller truck all the way to the landfill you are bringing it to a transfer station and maybe out of the material or of this 4 - 5 trucks, small trucks goes to 1 big truck because it is compacted as well and I will also show you some pictures of that, So at large distances is cheaper to haul waste in larger trucks than small trucks, so that is what I was trying to explain.

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So this is one example of a transfer station here the waste is so this elevation actually here is little bit higher elevation, you are at higher elevation here, so there is another road going from this height where the actually the big truck comes in here where the waste will dumped after the transfer station. The smaller truck will drive up to this point and they will unload the

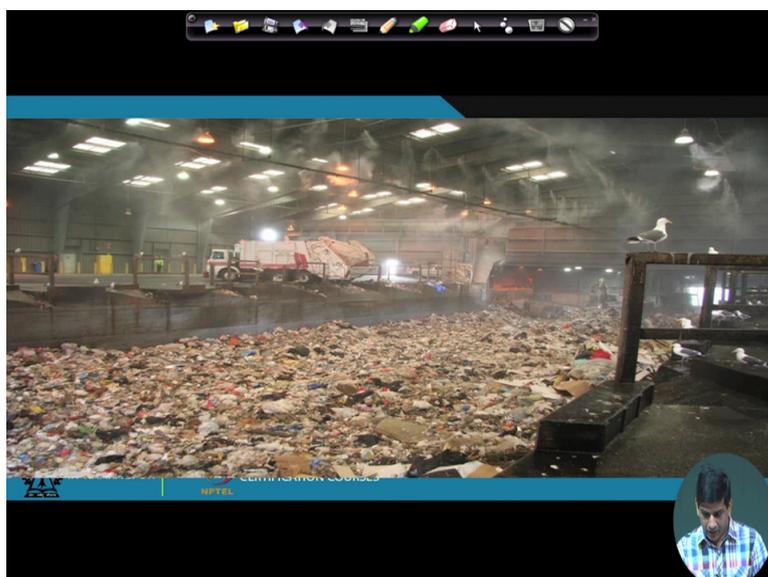
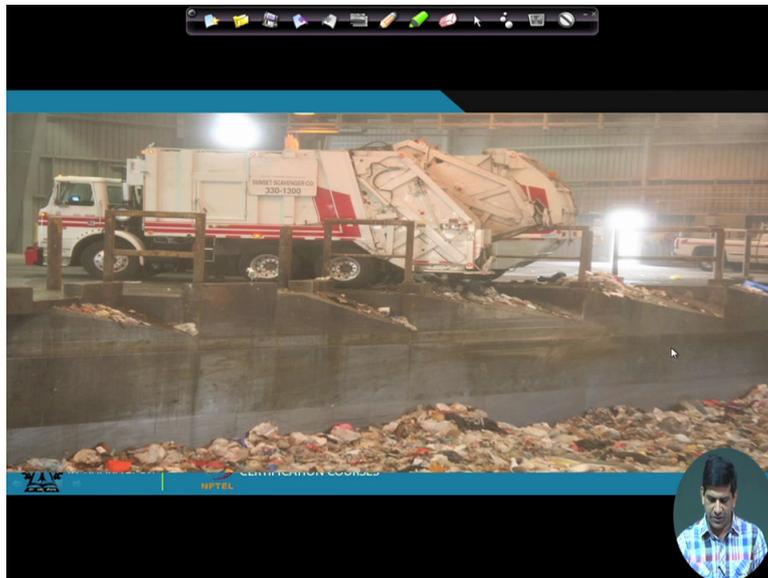
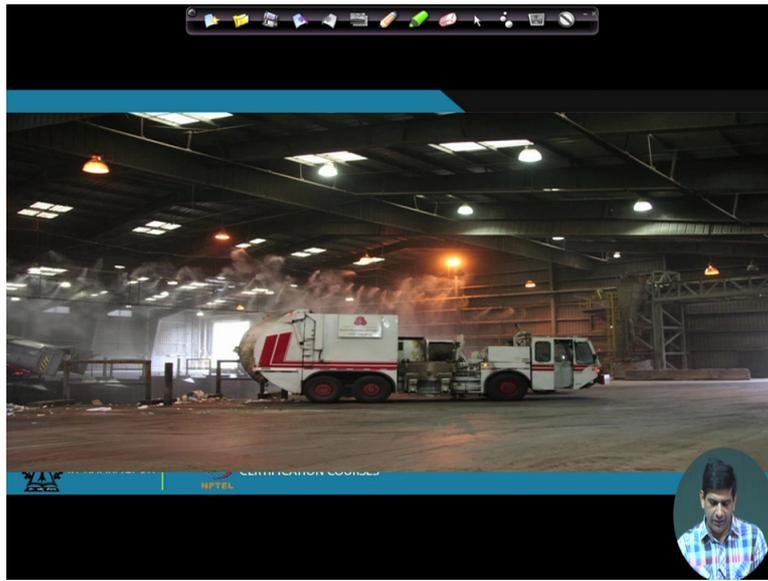
garbage and I think I may have the picture of that let us see, so this is one of this is the bigger truck which is at the lower elevation.

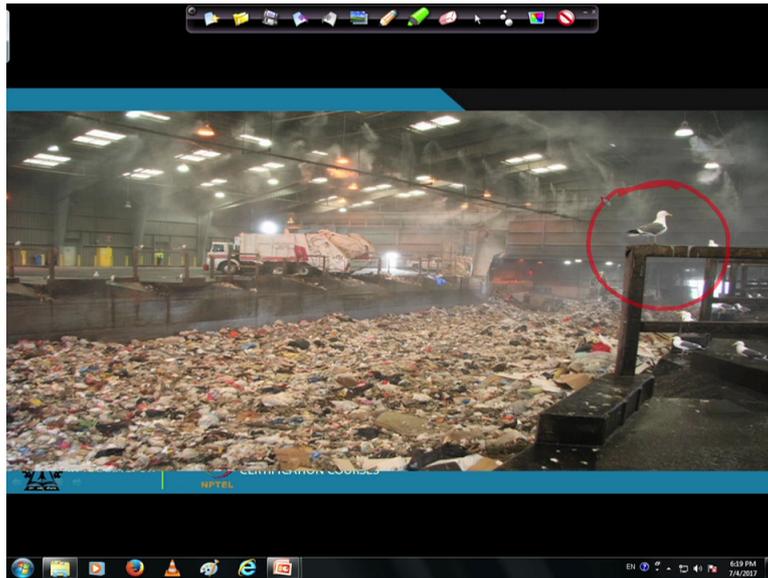
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Earlier we were seeing it from this side the only pitchers we saw was from this side, so this is so smaller trucks comes over there which is at this higher elevation, they dump the garbage and then there are garbage gets moved over here and then put into this because truck and compacted as well. So here the waste another transfer station in San Francisco California, similar concept is like small trucks coming in unloading it and waste getting into the bigger truck.

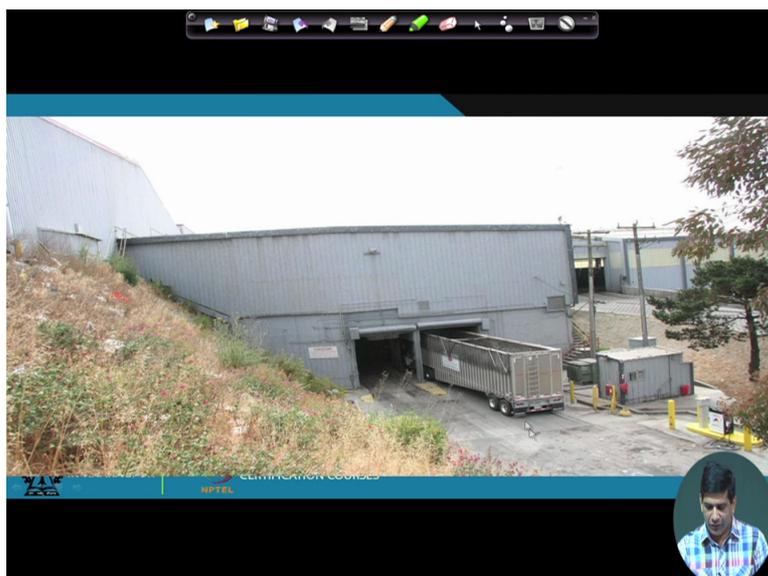
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So here this is smaller truck coming in and then they will unload the garbage and this garbage goes into this kind of a tunnel and this big trucks comes in and then gets into this tunnel and gets all these garbage and from there they will be lifted and these tunnel and put it into those bigger trucks and as can see as I told you several time if you really if you are interested in birds this is one place to go to go to a landfill or you go to transfer station you see a beautiful bird right there so if your birdwatcher go to a waste disposal site, I am just joking but we do seem good amount of birds over there, they gets attracted to all the different kinds of food there.

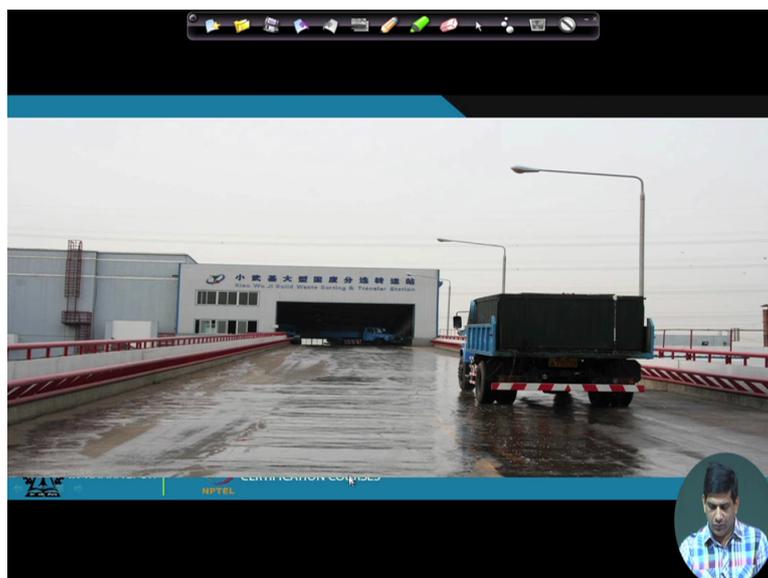
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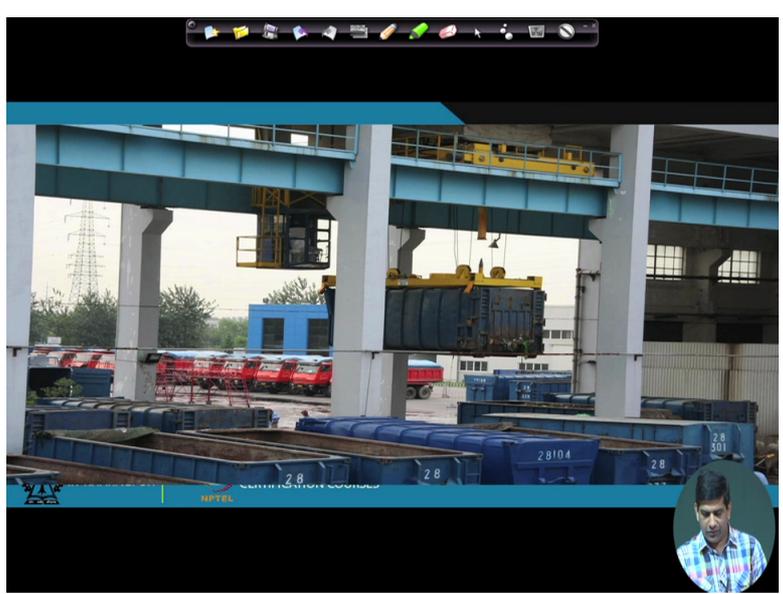
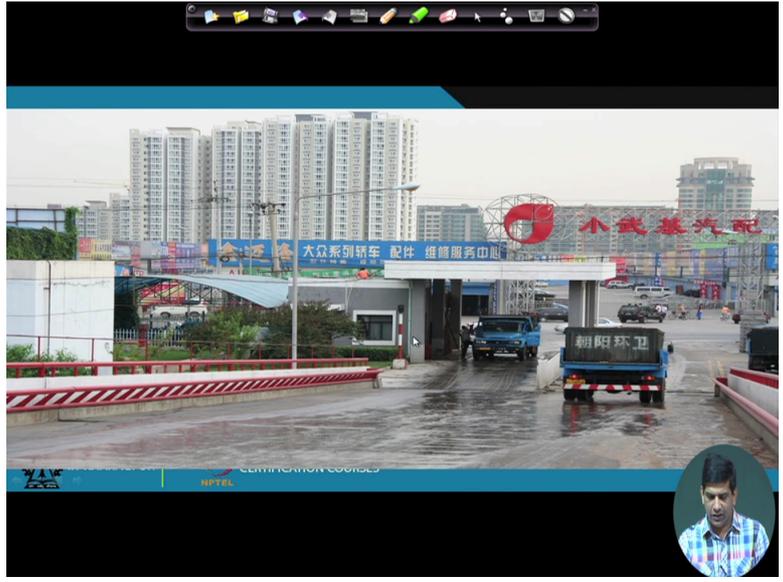


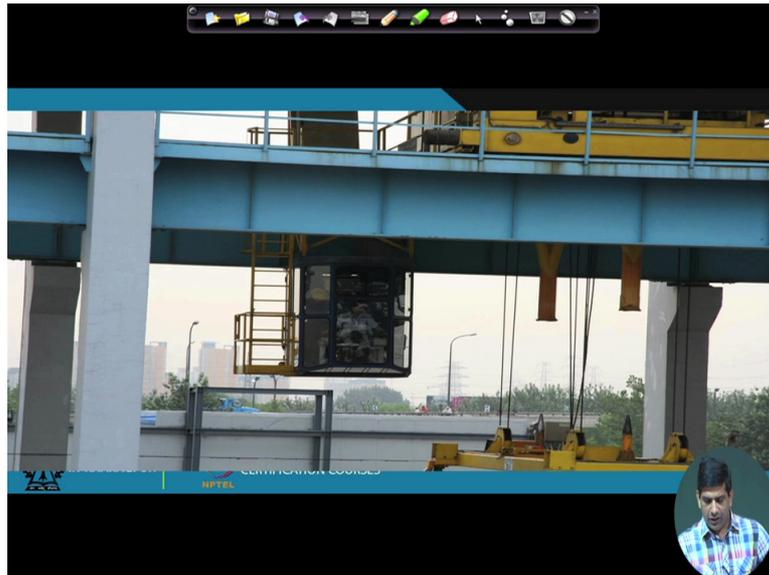


So this you can see all these garbage coming in into this smaller truck gets unloaded and then we have this bigger truck coming in and those garbage gets loaded into this bigger trucks and this bigger truck carries it to the landfill or to the waste-to-energy plant. So this is typically what is happening. This is another example of transition in Beijing, China. I was in China as well just during the summer break, so in China where this is this is Xiao Wu Ji solid waste sorting and transfer station in Beijing and kind of middle of a big residential area which you will see in the picture right now and this particular waste here.

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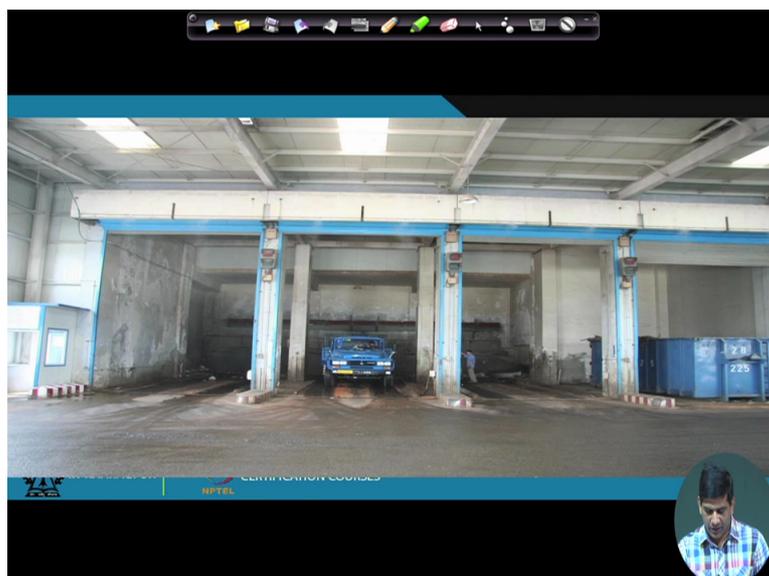


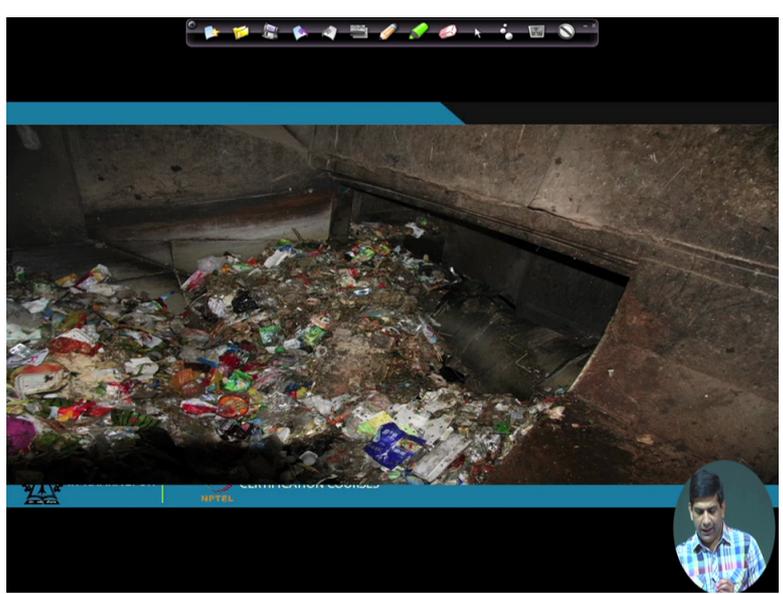
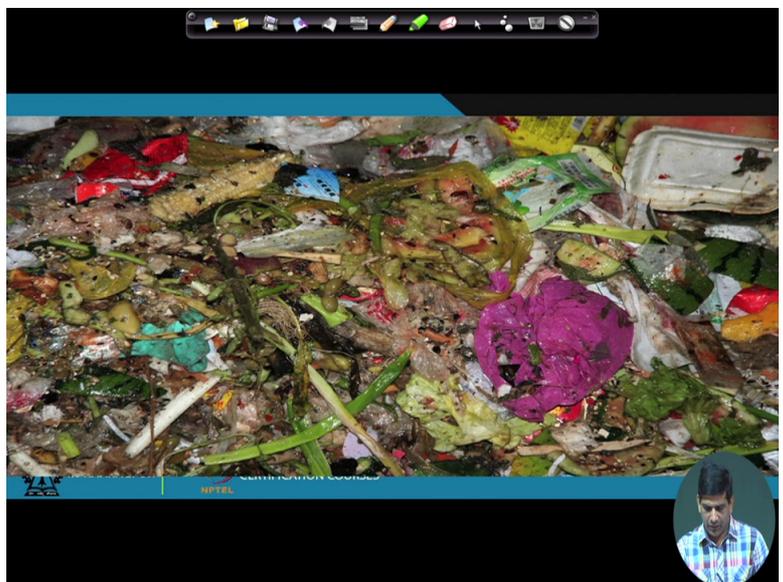
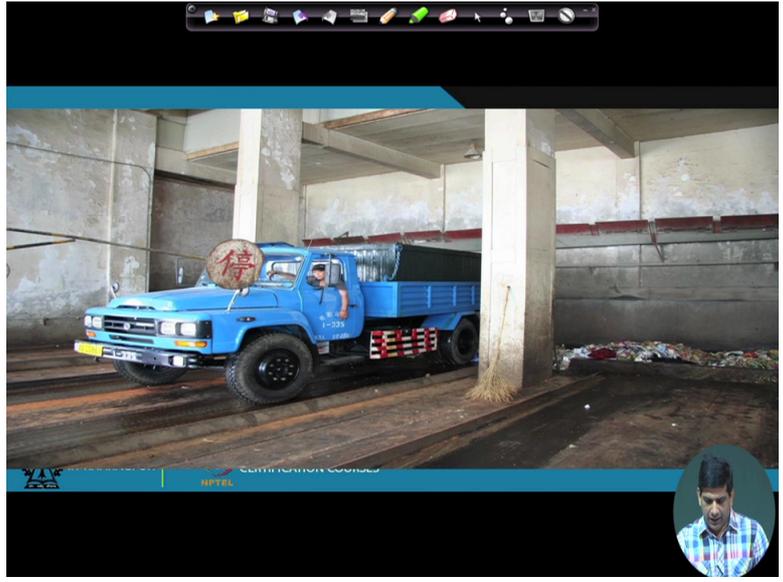


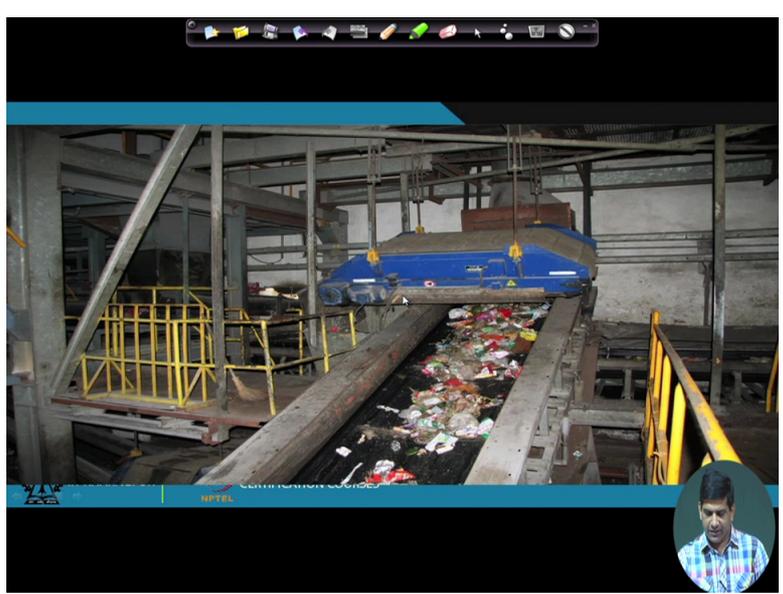
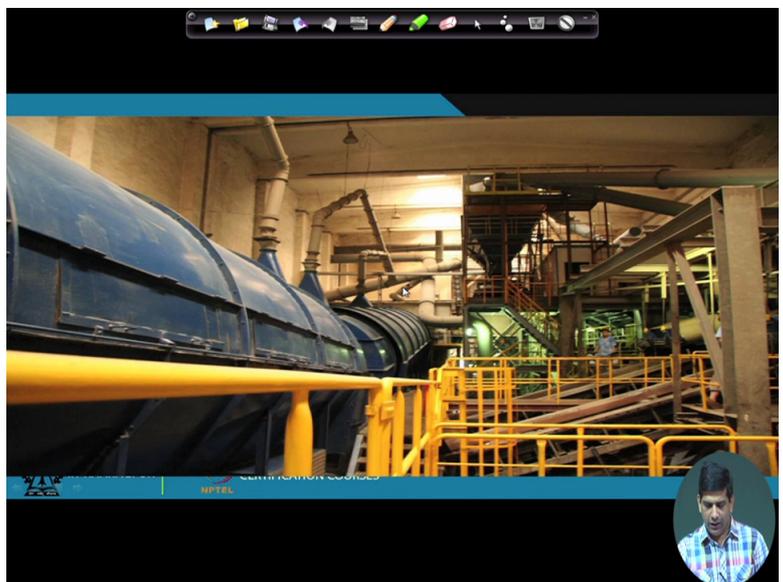
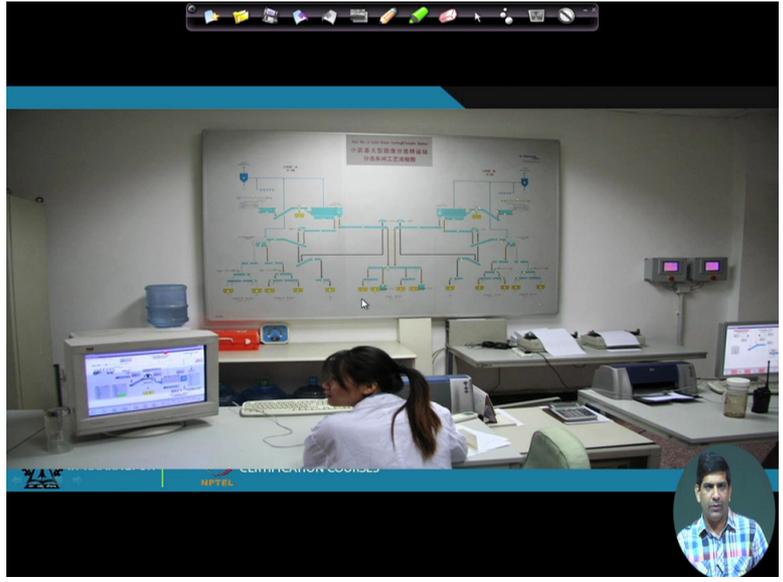


So this is like approach to that and they had food waste separation as well as you can see in this kind of very closed to a lot of high rise buildings but it smell and other thing was not there as well so probably it is it is okay, so this is the facility they have this waste coming in and then they will try to take the food waste separate the rest of the waste gets loaded up into these containers and then that containers are taken away for disposal, so these are containers that you were looking at, so this gets loaded up and taken away in for disposal at different places.

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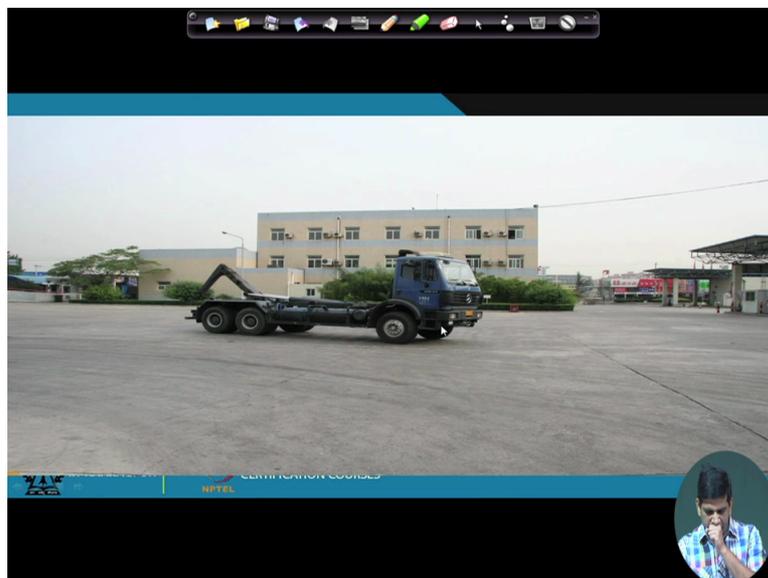
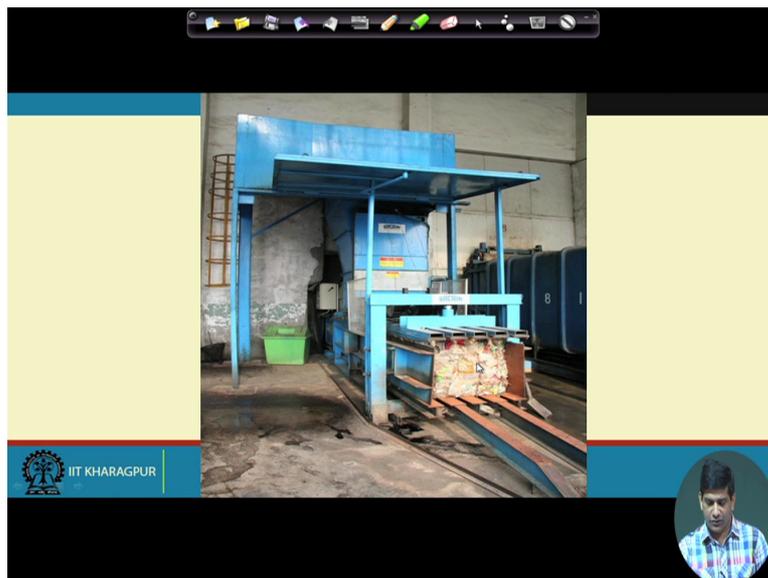






So here the smaller trucks comes in and lot of food waste that is being collected. This process through certain like a separation systems so you see some sort of crushing is also happening over here and here they are trying to separate organic from inorganic so that is they have try to separate the organics fraction of that is what they trying to do, so as you can see there trying to explain the different composition and then they have some screens and other stuffs, some recyclables shows up to, so those are the recyclables which do not show up.

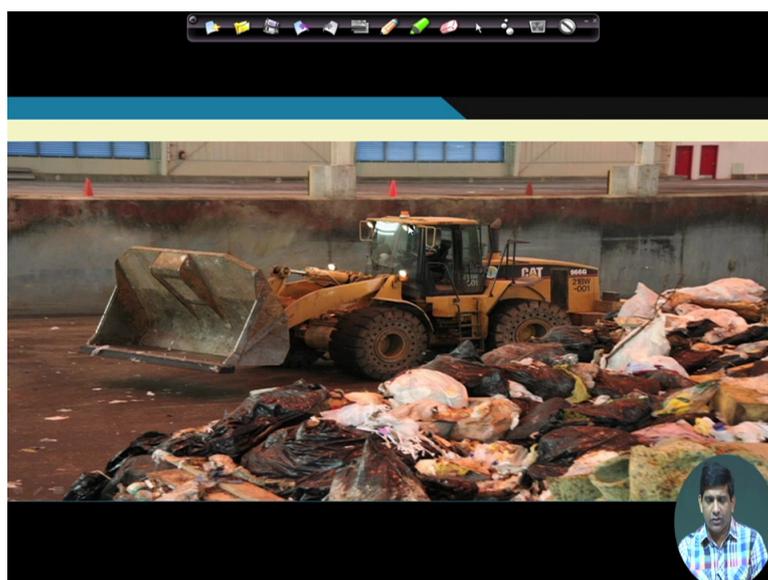
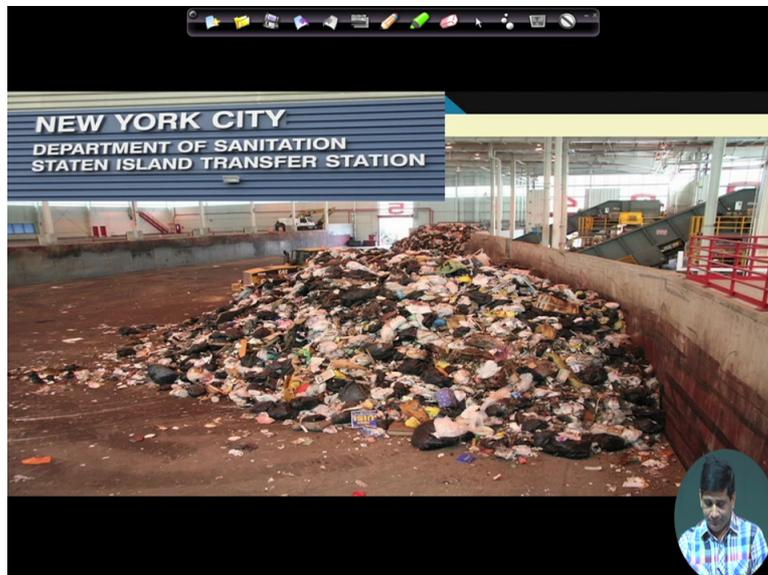
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Then some recyclables are (())(23:05) would be sold off and then those the waste stuff gets loaded up and then it is taken to another disposal or treatment facility. So transfer stations essentially like a, so as the name suggest transfer so basically the waste is being transferred from one truck to another truck and then the other truck the bigger truck carries it from the

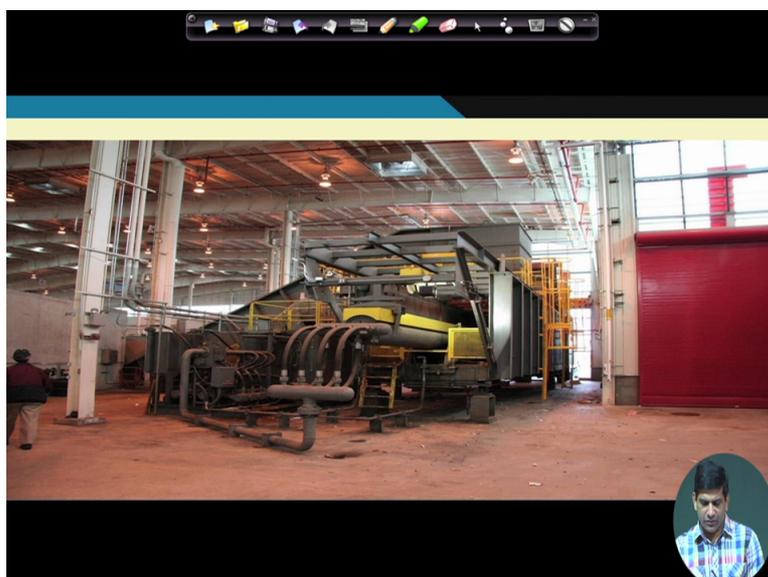
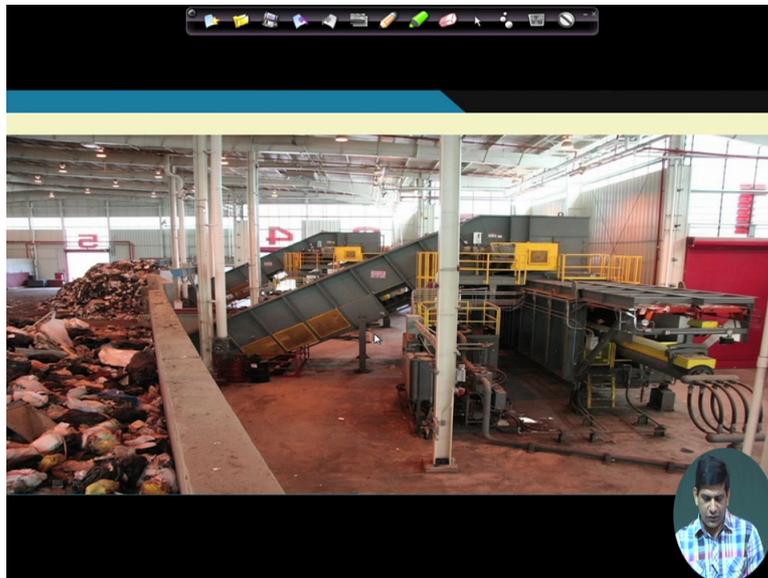
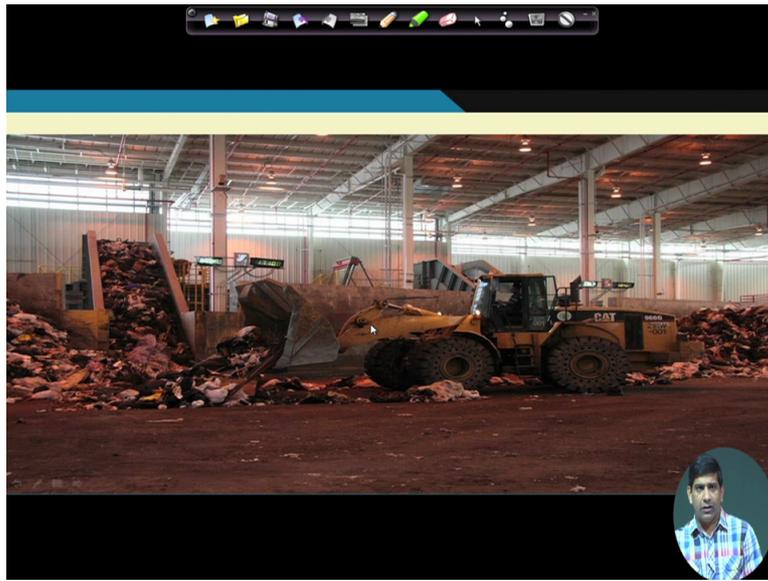
transfer station, so the waste is brought into the transfer station by smaller truck, waste is carried out of the transfer station by this bigger truck.

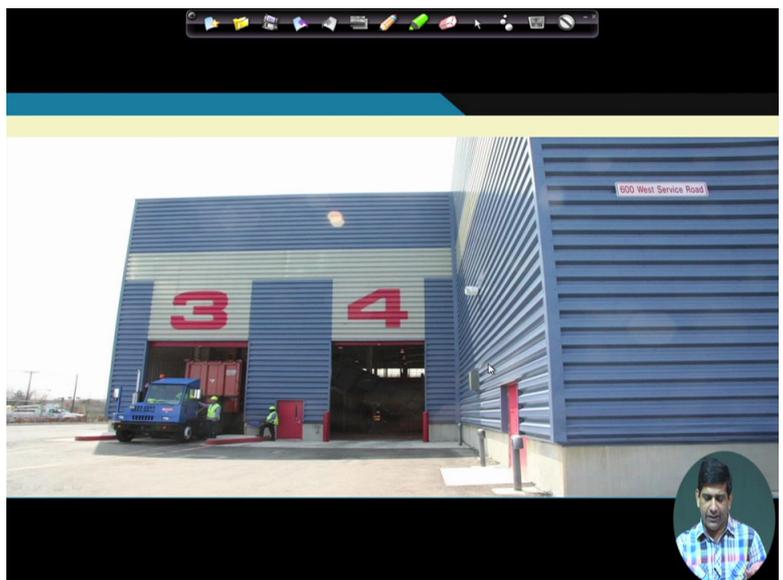
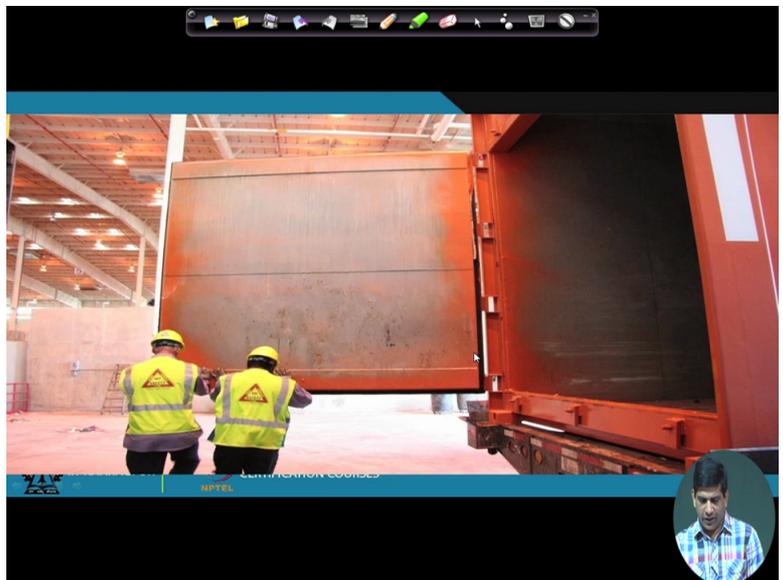
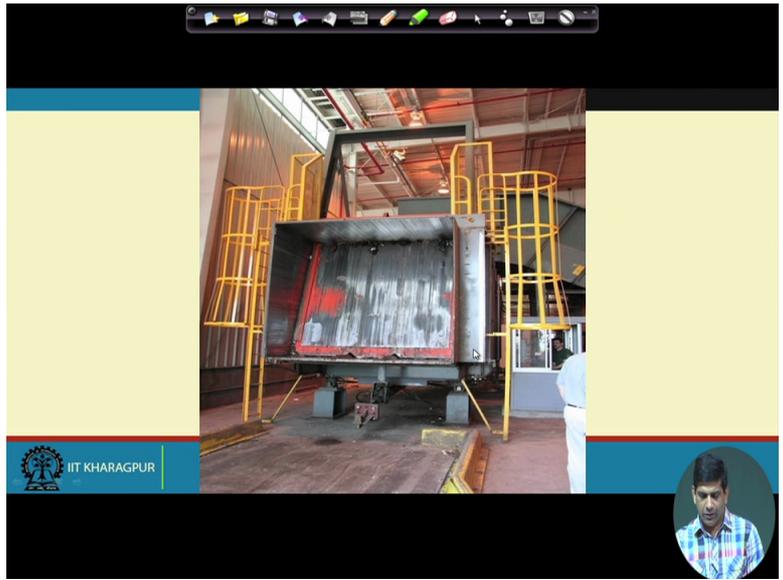
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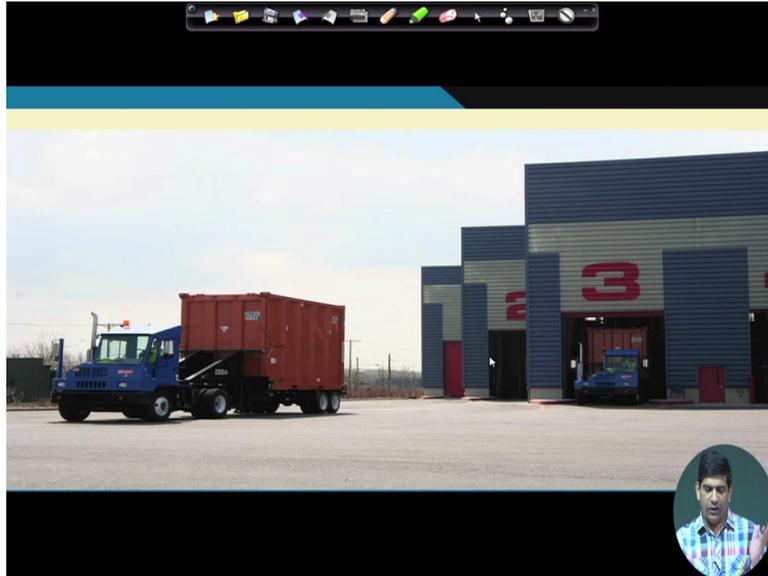


Another example the New York City Department of sanitation Staten Island transfer station, so again New York City does not have its own landfill, the Fresh Kill landfill which was closed long ago which opened after 9\11 but after that again it again got closed, so they do not have they have transfer station where the waste is collected and then some of the waste goes to Virginia some goes to Pennsylvania and some so whether to a landfill or waste to energy plant at different places gets distributed but New York as of today does not have its own landfill but it does not mean that not sending waste to the landfill, they are, so.

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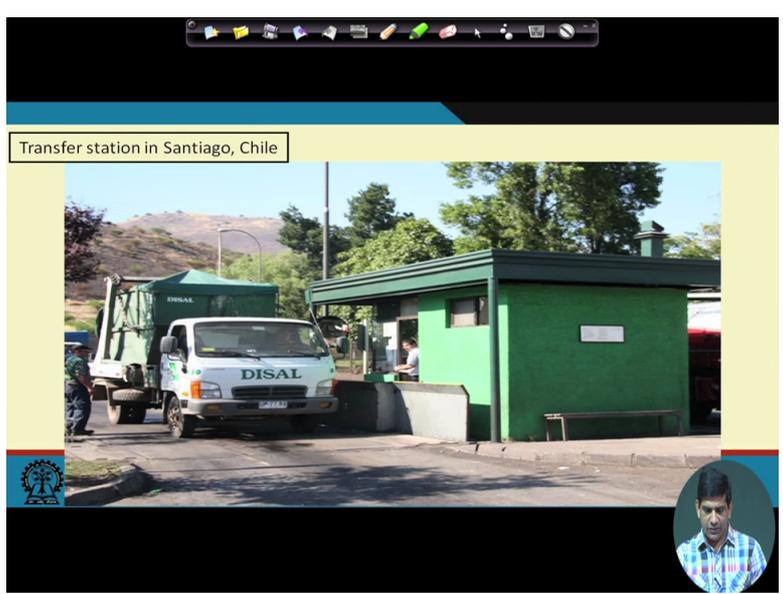
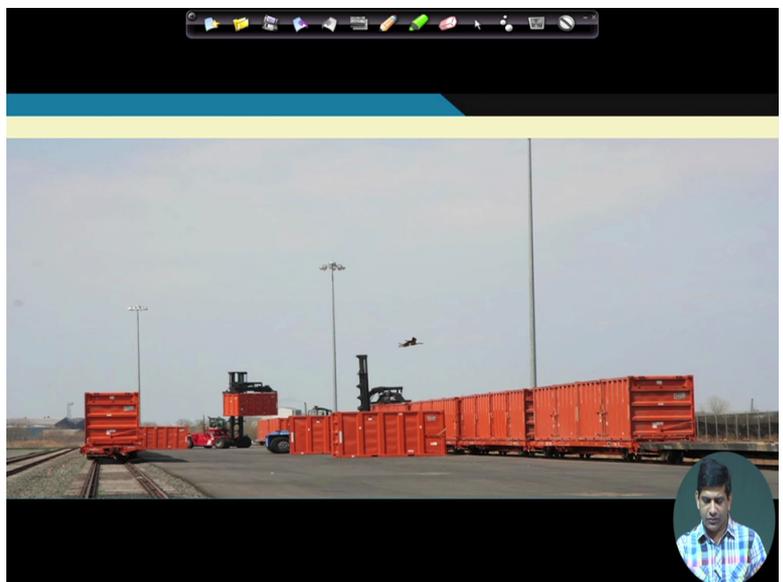
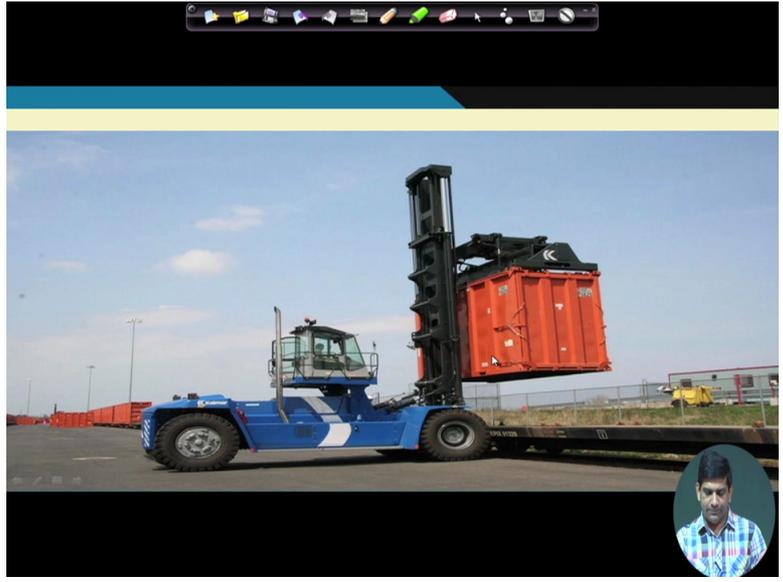




So this is again transfer station using the waste coming in you can see those like a different trucks you see here some of the compaction in the trucks on these particular point is where the pressure will show up and then this gets loaded up into some sort of this rail kind of container so this waste gets loaded up into this container then once that containers full we packet and then it goes in a train all the way to Virginia.

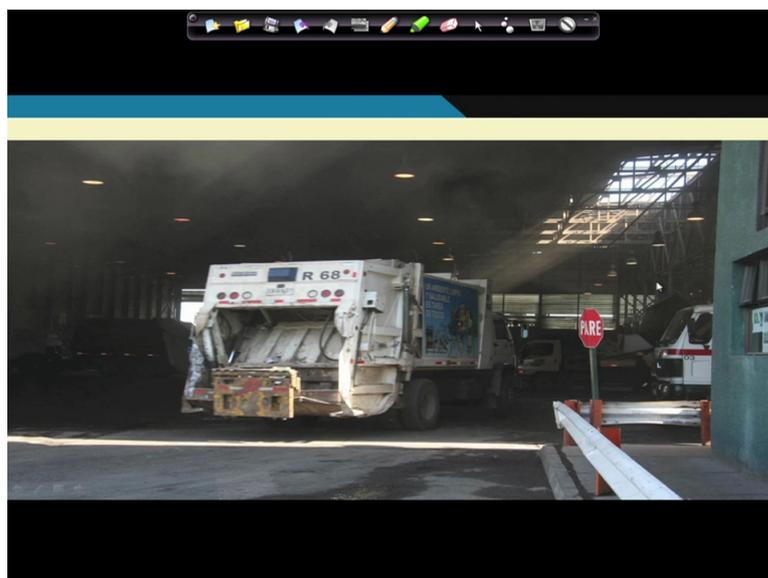
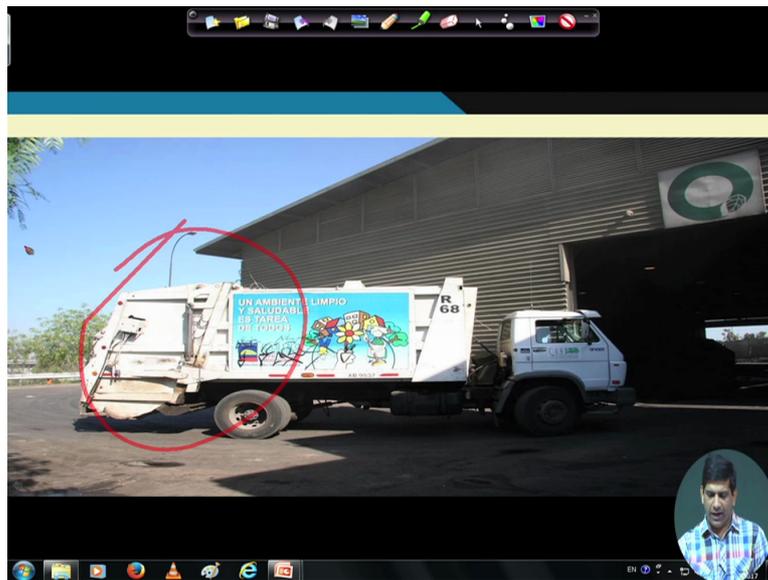
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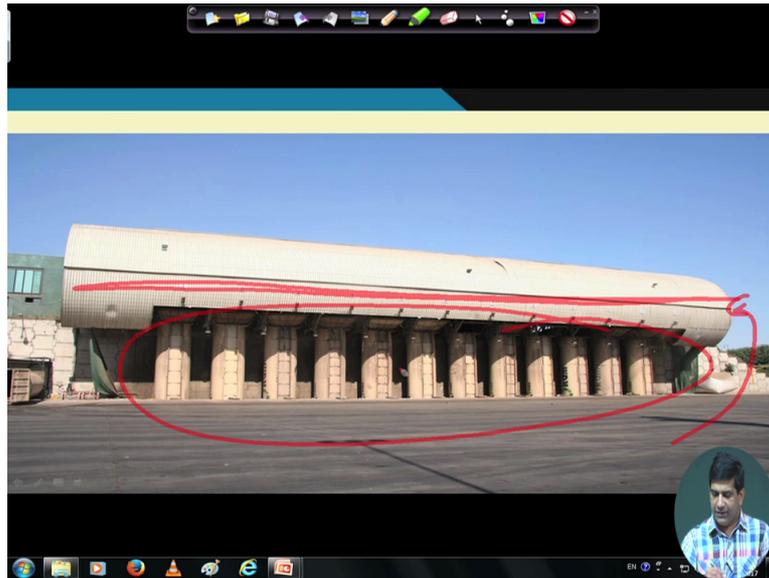




So this is getting loaded up and then it gets all the way to Virginia so that is how the waste is like in one of the ways of how the waste is being managed in the New York City, so this is some pictures of that. this one is very interesting one reason transfer station in Santiago Chile which is in South America and this picture is taken by my professor at University of Florida, he has taken these pictures and so he was there and this is a very cool transfer station. Waste does not mean things are not high-tech, things do get high-tech in waste management sector as well.

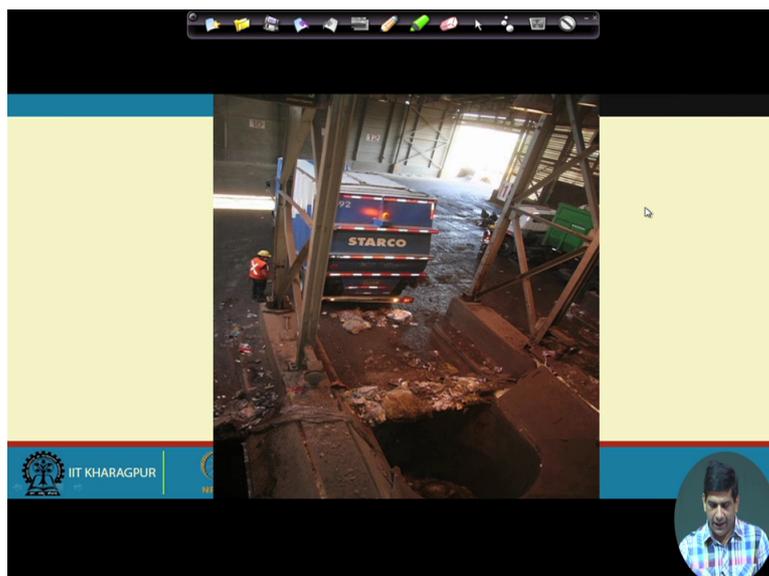
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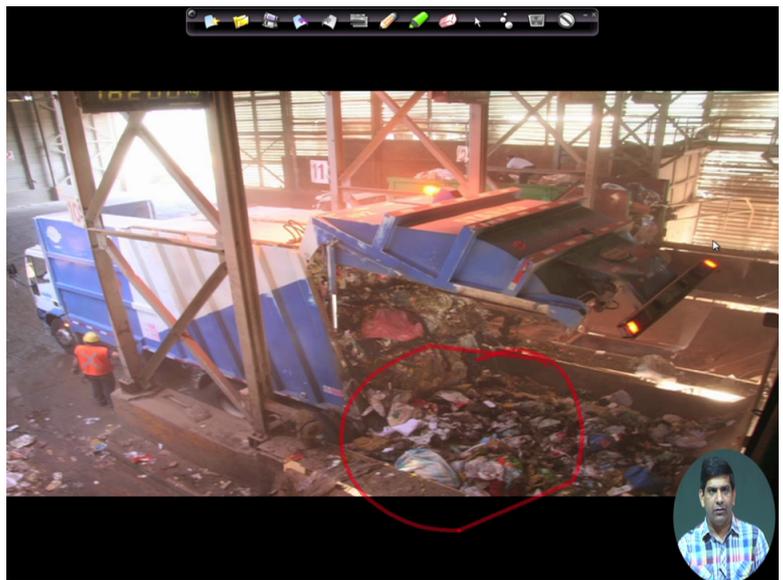
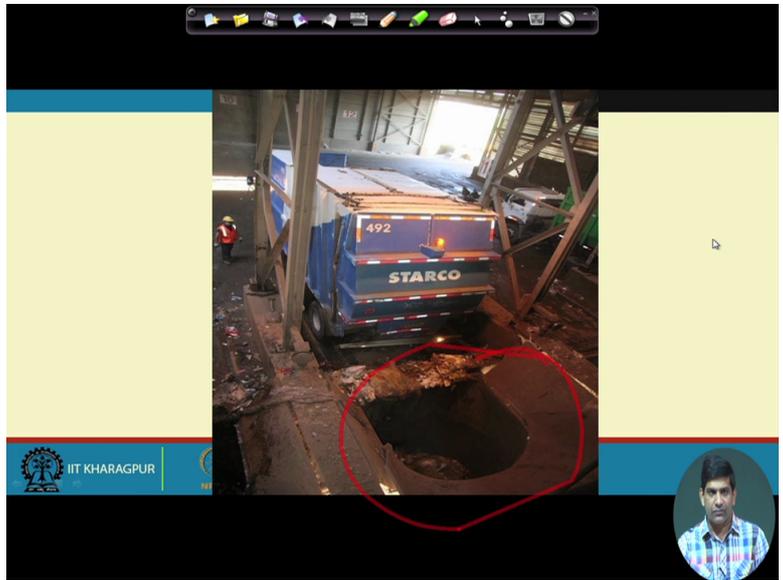
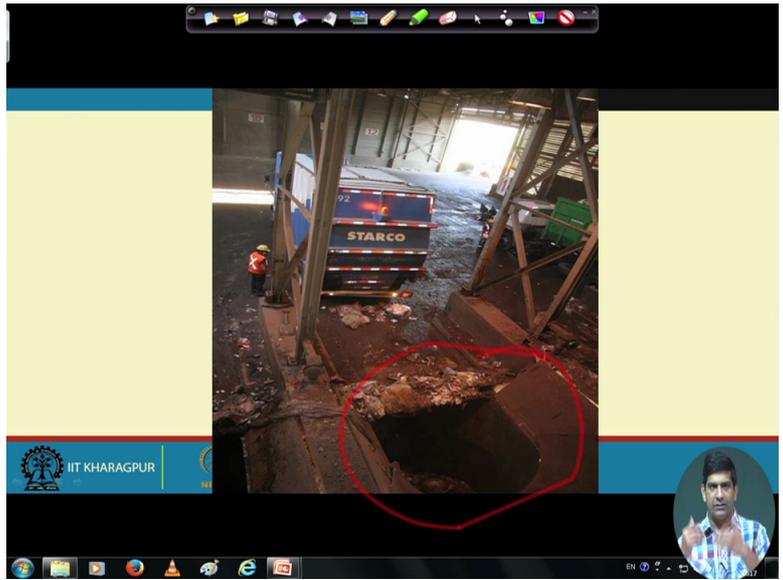


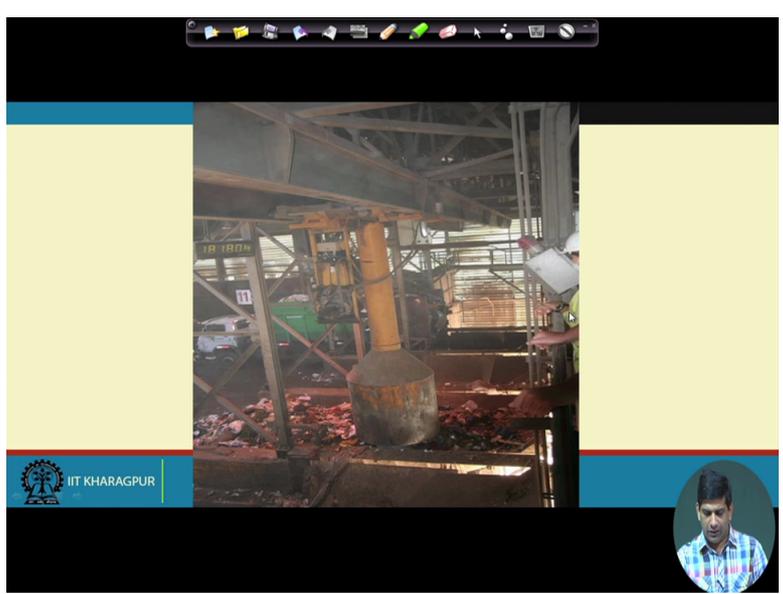
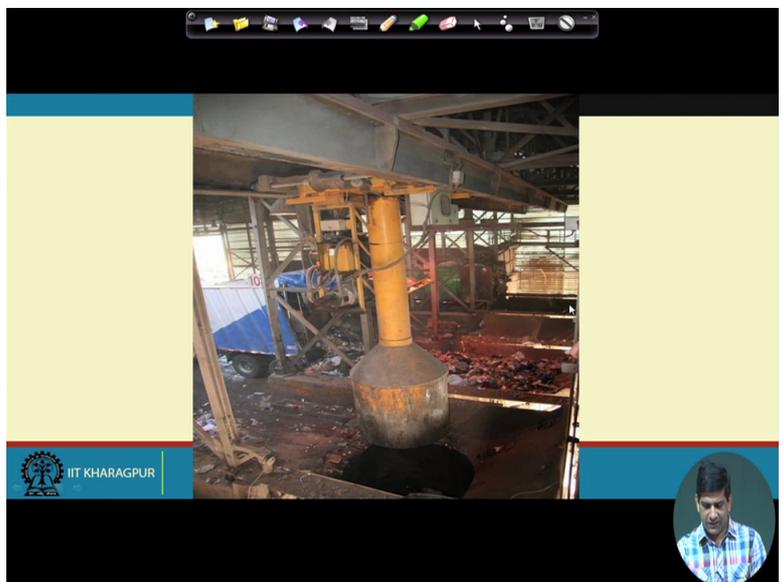
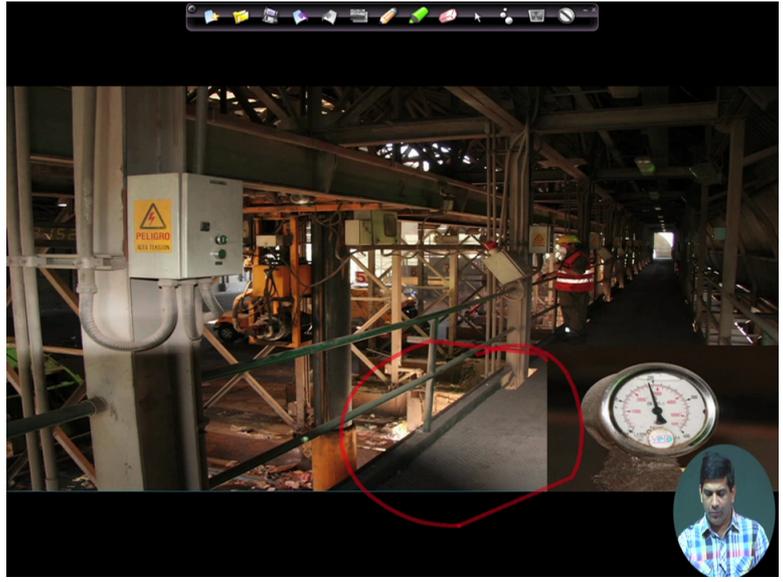


So here again this is a truck which has a compactor, many times in India now also you see these kinds of trucks showing up in many cities, so this has a compactor there which does the compaction so this truck is bringing in the garbage into the transfer station and then it goes inside the transfer station gets unloaded. Here what you are seeing actually those smaller trucks are coming at this level. The smaller trucks is actually coming in at this level on the other side so this is where inside this area is whether is smaller trucks are where they are unloading the garbage and what are these stuff over here you will understand in a minute and this kind of is a really a cool stuff and I hope you enjoy this pictures.

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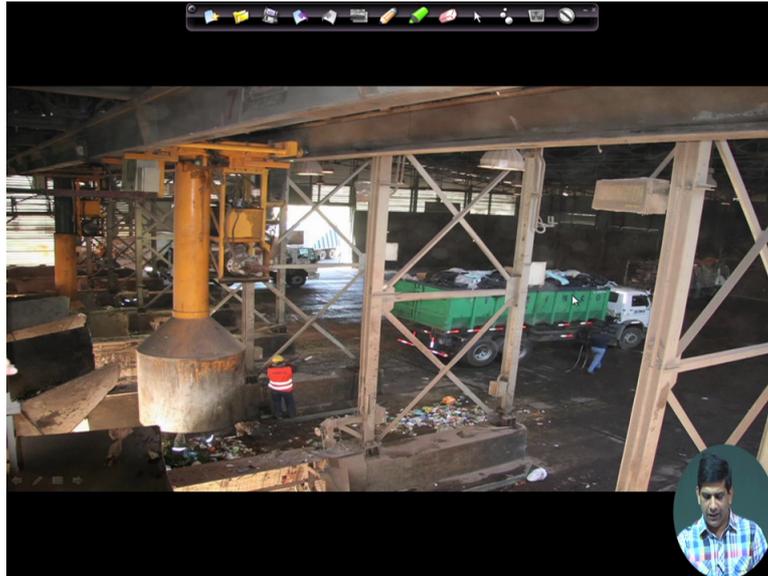


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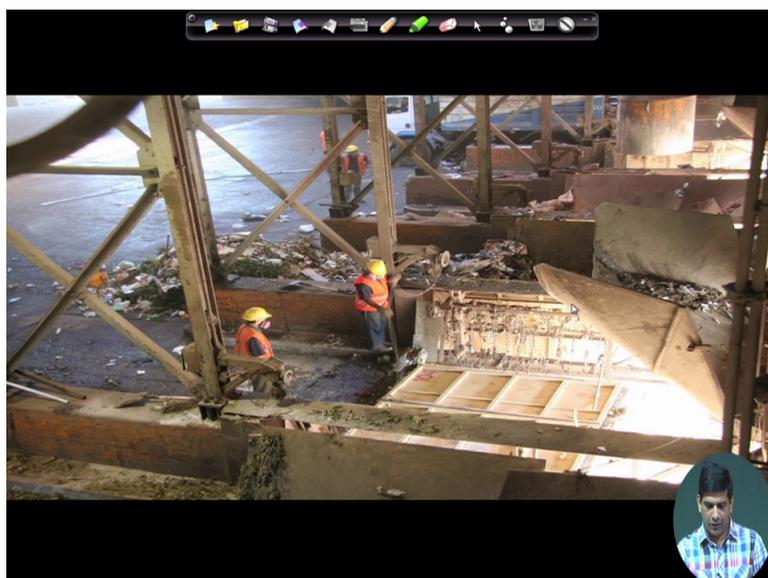
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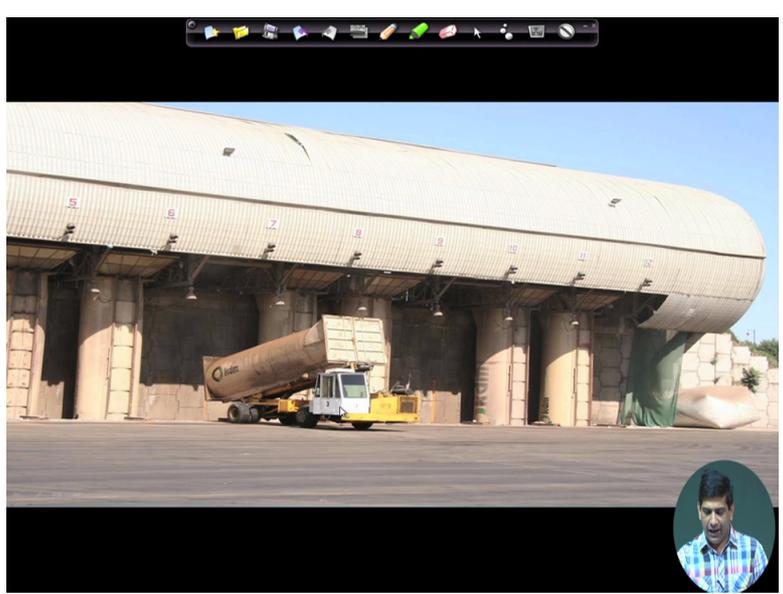
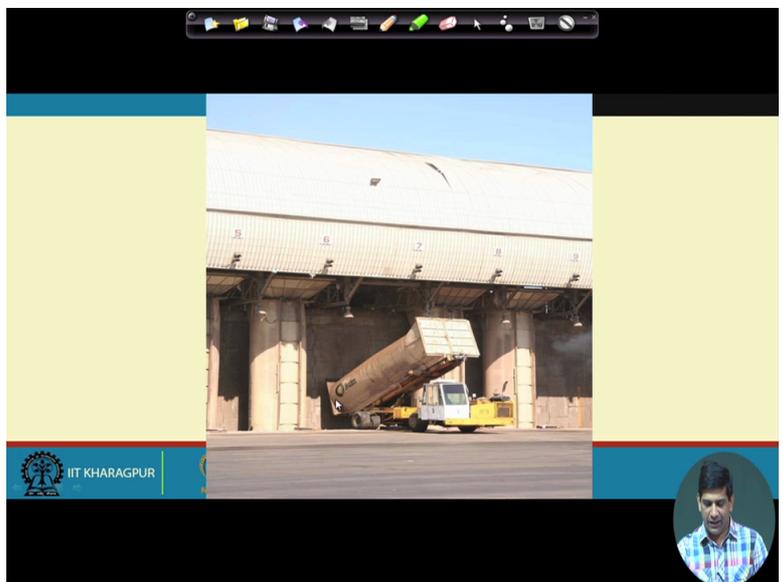
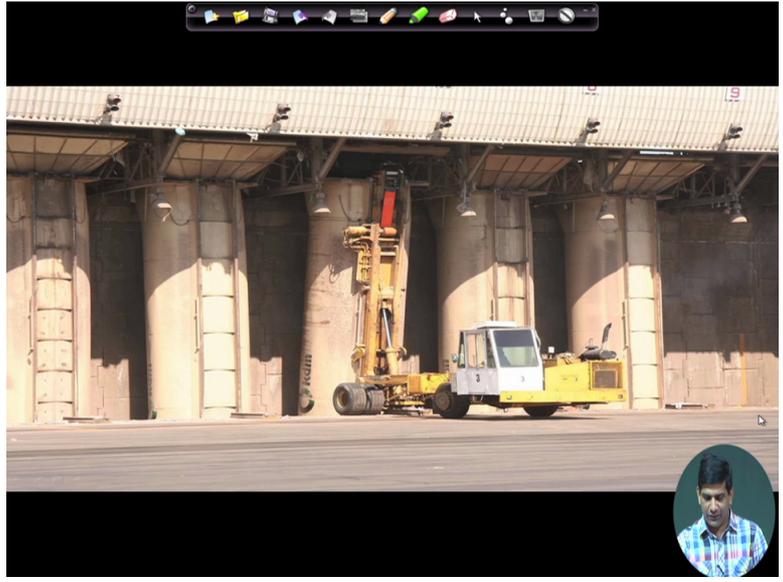


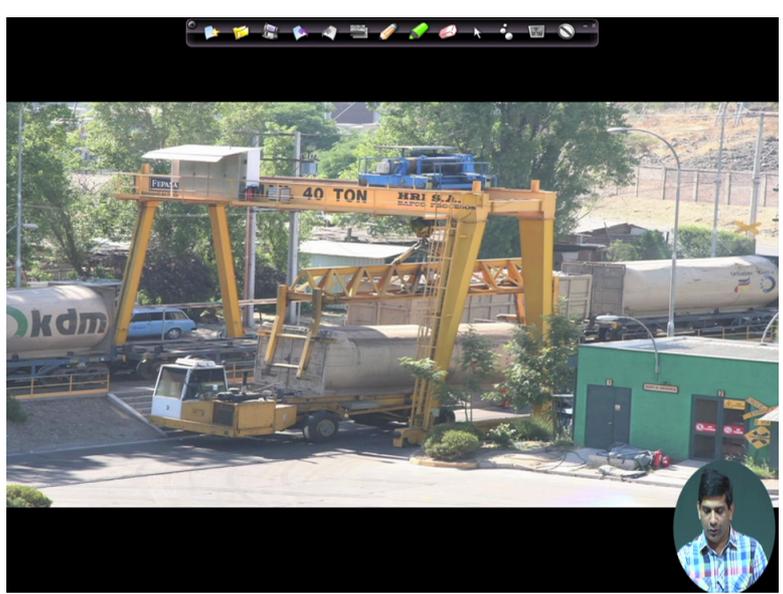
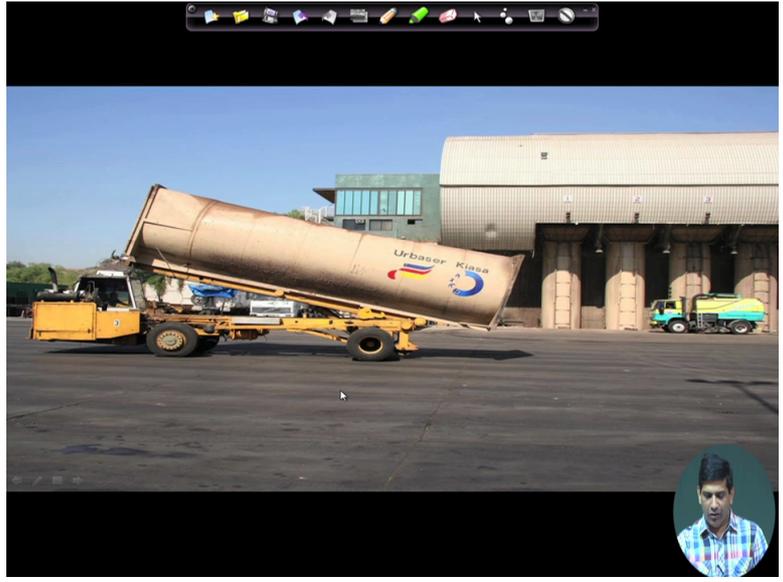


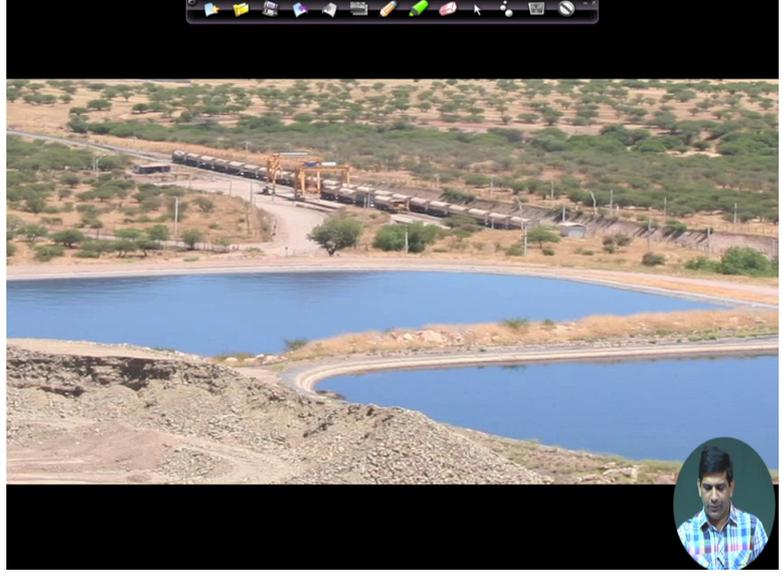
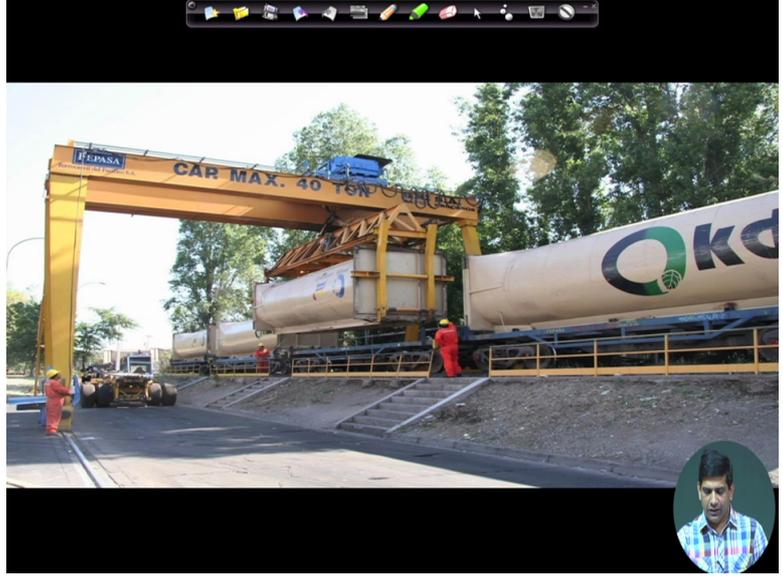
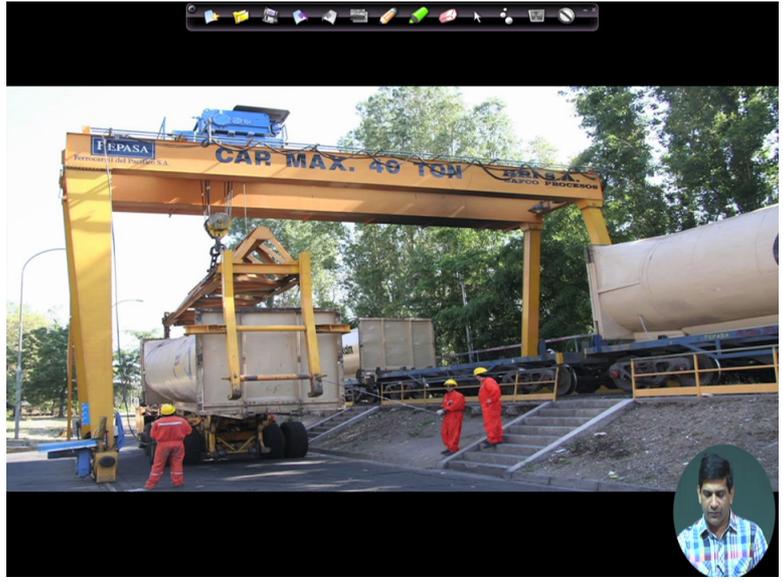
And so this is the waste coming in to the bigger higher elevation and gets unloaded, you can see the whole over here that is where the waste is being unloaded you see the whole, that is the waste well, get unloaded in that particular whole and as you can see so waste getting a truck coming in and its opened up they are opening the garbage and it is looking at the pressure terms of how much compaction is happening and this is your compactor right there and if you can see this is the compactor, it kind of goes in, try to compact and then once you can see it again over here.

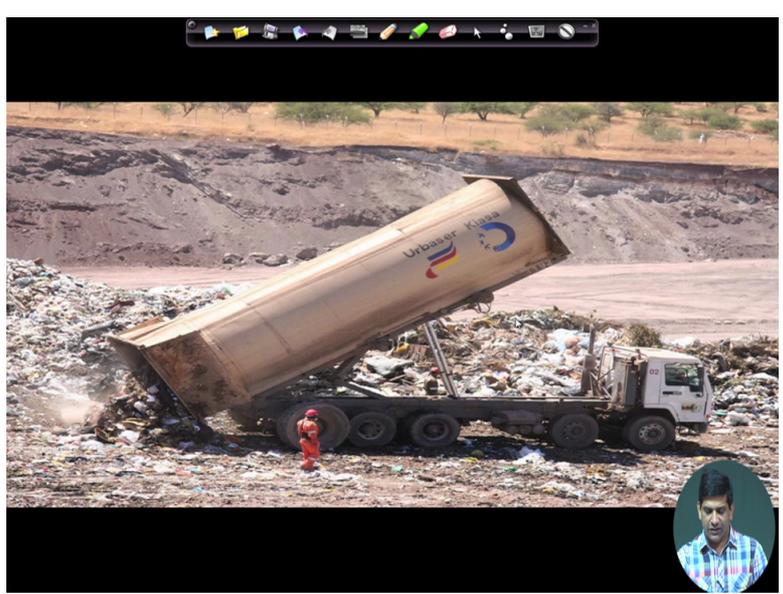
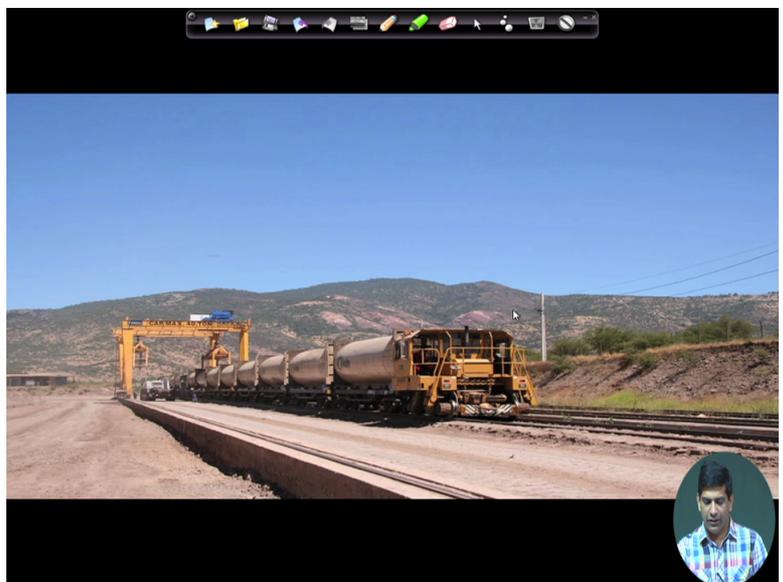
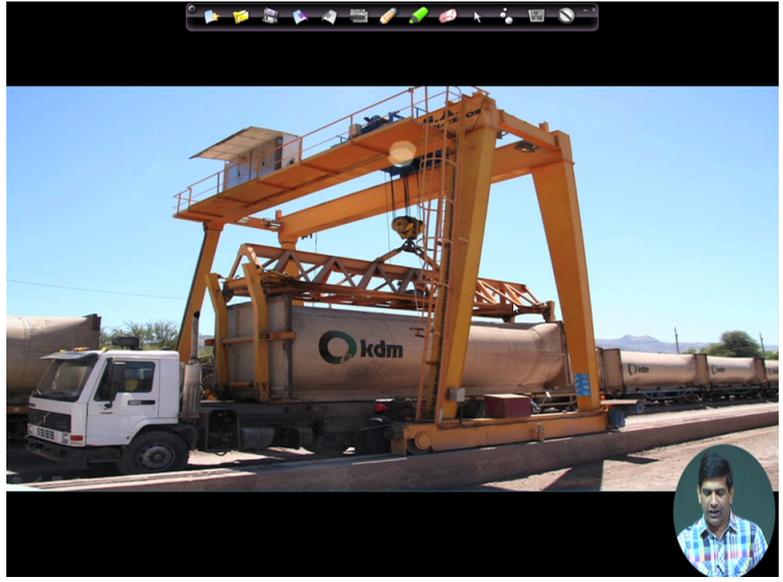
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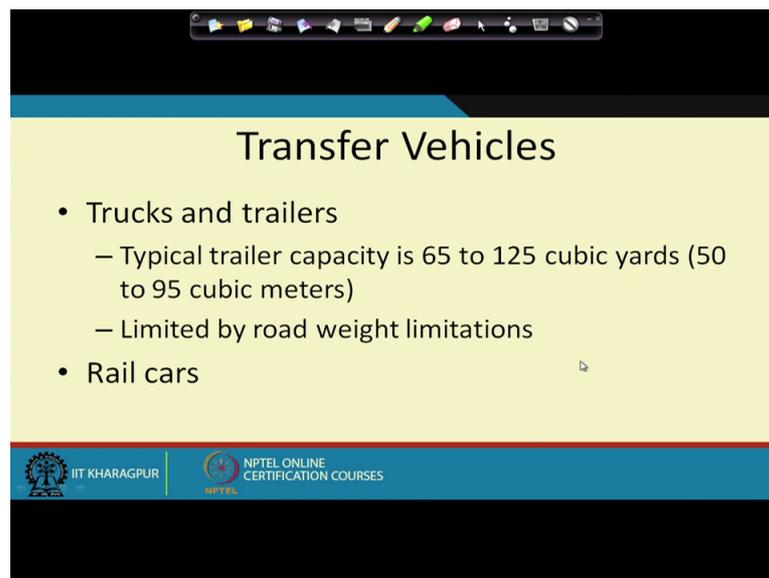






Once things are getting filled up you put a cap on it and now if you go outside and try to see it this is the cap was right over there. So these are kind of (())(27:20) kind of structure is actually big containers for transporting garbage, so this will be taken off and put it on the rail and then it travels nearly 300 km away so it is getting on top of the rail and then it is loaded up and then it travels around 300 km to the landfill site where the landfill site it will be unloaded, once it reaches the landfill that is gets dumped onto the landfill site, so pretty cool.

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Transfer Vehicles

- Trucks and trailers
 - Typical trailer capacity is 65 to 125 cubic yards (50 to 95 cubic meters)
 - Limited by road weight limitations
- Rail cars

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So this is again just managing garbage at different places and if you go on YouTube if you go on look at the other stuffs are funny and interesting stuff you will say in terms of the waste collection and waste collection system, so here the landfill coming out. So in transfer vehicle there are different trucks, there are trailers, typical trailer capacity the big one is around 50 to 95 cubic meters it depends upon the road weight limitation because DOT specially also in India like Department of Transportation has certain limitations, so in terms of what how much heavy truck can go on road. Things are also moved by rail cars and that is how it is done as well.

So this is how the waste is collected and waste is transferred. Next we will look at where we can go for transfer station like we will try to do an engineering economic situation where how to decide say for my city should I go for a transfer station or should not I go for transfer station. So try to and I think I have math problem in one of the slides just few slides from now, so we will do that in our next video will spend time on try to understand this engineering economic issue and we will do some other math stuff associated whatever we

have talked about so far and then once we are done about that then will move to other chapter.

So again I hope that you are enjoying the course and do let us know if you want us to if you need anything from us, we have been providing you with PowerPoint slide as a PDF file then spin some ready material have been posted as well. There is lots of material available on the web through Google we can download lots of reports and other things are there. There is a global waste management outlook if you are interested in it was done by world bank, it is a global waste management outlook 2015, so 2 years ago they did that and I think the next one will probably welcome in 2020 I am not sure the but I think that it comes every 5 years.

So if you look at that it is a very good document, you can download it for free and it is available you Google it global waste management outlook 2015 and you will find the documents, so you should read the documents and that gives a very good overview of how the waste is situation around the world, so that is always interesting to know that how our waste management situation compares with the other countries and what they had done which we can learn and do it over here.

Not everything can be situations are different in Western Europe and countries or American countries or over here but there are certain things certain good practices and be taken and can be adapted for the Indian condition. So we keep on talking about that in rest of the course as well, so with that lets close this module right here and then again I will see you in the next module. Thank you.