Urban Services Planning
Professor Debepratim Pandit
Department of Architecture and Regional Planning
Indian Institute of Technology, Kharapur
Lecture 25
Routing and scheduling for solid waste vehicles Part II

Welcome back. In lecture 25 we will continue with Routing and Scheduling for Solid Waste Vehicles. This is part two of the lecture.

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The different concepts that we will cover, first we will start with a case study of solid waste transportation model for Asansol. Then we will talk about the distribution problem, vehicle routing problem, optimization techniques for vehicle routing problem. Then we will solve the vehicle routing problem, VRP and traveling supplement problem in ArcGIS. Then we will use the network analyst module in ArcGIS for explaining traveling assessment problem and the vehicle routing problem.

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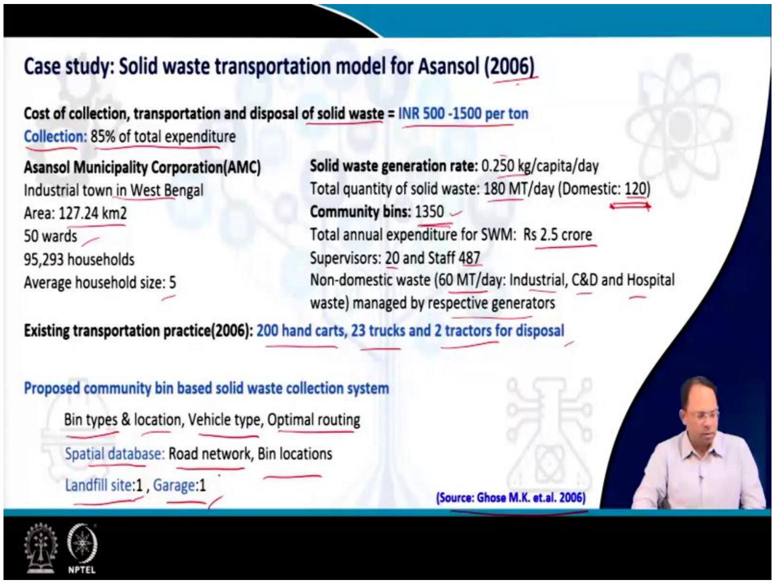

So, as we have discussed earlier that solid waste collection is the most costliest phase of the overall municipal solid waste management system and as you know estimated in this particular study it it says that overall collection and transportation disposal of solid waste in India, this is of course done for the year 2006, a little bit older data, but ranges around INR 500 to 1500 per ton and out of that 85 percent of the total expenditure actually goes for the solid base collection system.

So, this study actually talks about the Asansol municipal cooperation, the solid waste and it proposes a new collection system for this particular cooperation and it shows us how the collection system is designed. So, I will also explain you that particular proposal that they have given and how they have built that proposal.

So, then we will explain based on that what sort of algorithms could be used and so on. So, Asansol Municipal Corporation is an industrial town in West Bengal, area as you can see is around 127 square kilometers, it includes 50 Watts, 95 000 or almost 1 lakh households and average household size is around 5.

Now, Solid Waste generation rate for the year 2006 was estimated at 0.25 kilograms per capita per day, probably this value is increased a bit. Now, but still it is acceptable figure and total quantity of solid waste is around 180 metric tons per day out of which 120 is domestic solid waste and 60 metric ton is non-domestic.

Now, non-domestic means industrial construction demolition and also hospital waste and usually these are less managed by the respective generators and so these are not addressed in this particular study. So, only this study addresses the solid waste that is generated within the city area and some from market, some for complexes and some from the residential areas.

So, total number of bins that are considered is one thousand three hundred fifty and this bins are of different sizes that we will consider. And total expenditure is around 2.5 crores, total supervisors for this particular area is around 20 and total staff is around 487 and this community bin system was initially present over here and usually during this time around 200 hand cuts 23 trucks and 2 tractors were used for disposal.

So, this was the basic system which was at that point of time being utilized and this study proposes our alternative system which is better compared to what was there earlier. Now, what this study proposed? It proposed different new types of bins and their location instead of standard community bins which was there earlier then vehicle types, it also proposed new vehicle types compared to what was there.

And also the optimal route for this particular vehicles the initially the spatial database was created that is the road network and the bin locations, this were actually put on the map itself and the location of the landfill site and garage both of them one landfill site and one garage is being considered.

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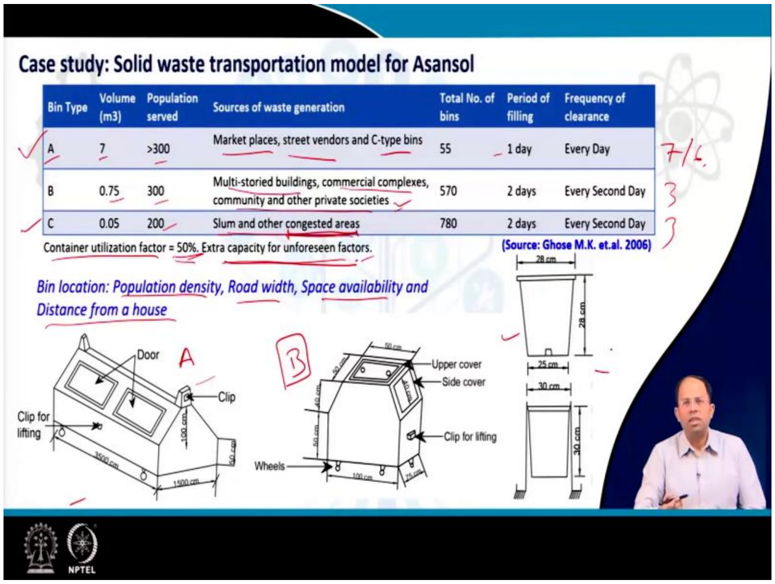

Now, what kind of binbins are considered there are three categories of binbins are considered door to door is not considered over here. So, C type. So, you can see that the bin type A with volume of 7 meter cube which is thought to serve a population which is more than 300 and it is located at marketplaces, street vendors, you know locations where there are a lot of street vendors.

And the content of C type binbins are actually transported to A type bins, that means A acts as the secondary storage for garbage collected from C type bins and C type bins are put in slums and other congested areas that means these are the residential areas where you know smaller vehicles collect this particular euro garbage west and then bring it to this larger bins.

So, that they could be transported by a larger lorries. Now, now, as per MSW 2016 we cannot have this kind of a system we have to have door-to-door collection but over here it is stated that it is a community bin level system that means this bins are provided in close proximity and serves around 200 people approximately for an area.

Now, we can say that now this kind of system is not relevant but you have to understand in today's context also there are many places in the city which has got slums and are congested areas where we cannot do door-to-door collection and there is no other way than to put a community bin over there where people come in through garbage.

So, in that case also if we design a system which is both we have got door-to-door collection as well as some amount of community bins in that case collection from the community bins could be brought to the storage points which are the large C type bins which are provided in places such as marketplaces street renters the places where there are a lot of other you know generators.

Now, B type bins are present which is serves around 300 people volume is around 0.75 meter cube and the volume the size C bin is even much much lesser which is 0.05 meter cube and you can see that these are placed in multi-student buildings commercial complexes community and other private societies.

Which is also the practice these days that means this kind of bins are placed over in this kind of societies where the society's garbage come and from there the principle to collect this garbage. So, the frequency of cleaning for a type bin is daily whereas the frequency of cleaning for the other two kinds of Bin is every two days. So, that means around three times per week and whereas this is done seven days or six days per week.

So, the size of the containers that is being decided we it is assumed that the container would be utilized to 50 percent and extra capacity is given for unforcing fact factors for example sometimes there is stoppage of the surveys because of some issues or there is extra waste generated during some sort of events.

So, so all these are being considered for this like one day people did not throw garbage but in the next day you know many families came out because of whether and all they have not thrown the garbage on Bali a day but in the next day they are coming and throwing the rubbish for two days. So, all these factors are considered as unfortunate factors and that is why container utilization factor is taken as fifty percent three kinds of continuous as we have discussed container type A this is the large container, container type B this is like those four wheeled containers.

That we have discussed earlier these are kept for larger generators and this is container type c which is in the locally you know in residential areas this kind of continuous circuit and bin locations are based on population density road width space availability and distance from a house. So, wherever roads are wide the larger bins are provided where roads are smaller than smaller bins are provided. So, this is more or less the system this particular study is proposing.

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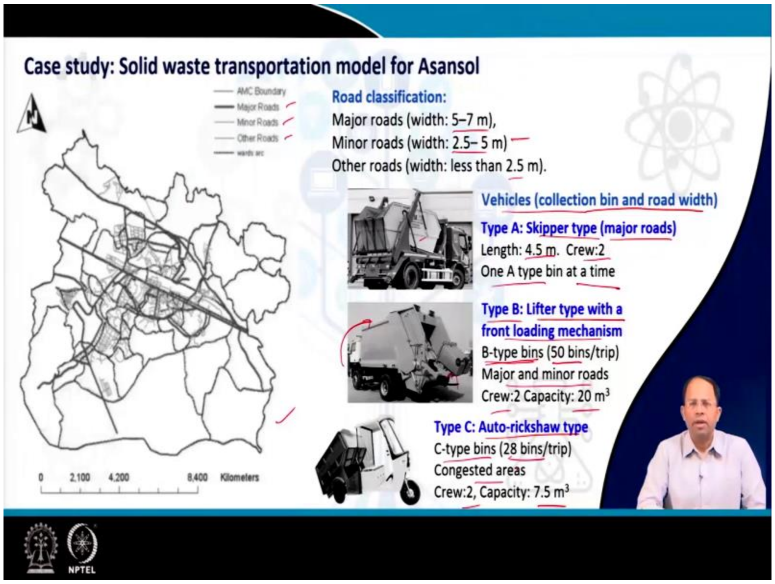

Now, to do the study of course you have to do the first we have to code the road network that means we have to first prepare the road network map as you can see the major roads, minor roads and other roads are big mark and major roads are wider ones minor roads are the 2.5 to 5 meters whereas other roads are even smaller roads.

So, all types of vehicles cannot travel in all roads. So, whenever we generate the routes for vehicles and all we only considered the relevant we considered the relevant road networkers that are acceptable for that kind of vehicle. So, similar to three kinds of bin three kinds of vehicles are considered which is vac and this is done as per the type of collection bin and the road width in which roads this will travel and what sort of collect bins they will collect from.

So, type A is a skipper type vehicle which flies along the major roads their length is around 4.5 meter they take a crew of two and usually they lift one a type bin at a time like over here they have lifted one of the bins and once it lifts it, it takes it to the disposal side disposes the bin and then again comes brings the empty pin and places it back into that particular area then moves on to the next bin.

Type B type of vehicle this is a lifted type vehicle with a front loading mechanism. So, over here you can see a back loading mechanism but this vehicle has got a front loading that is that they are proposing. So, more or less similar kind of vehicle where you lift the garbage bin and unload the garbage inside the vehicle and then then it may be a compactor vehicle and it further compacts the garbage. So, in this kind of you know this type of vehicle colors garbage from B type pins and like for example it will go from each you know each society to society or each get it complex to another gated complex and keep on collecting the garbage.

So, it is able to collect garbage 50 bins in one trip that means as per the capacity of the vehicles it is able to take in 50 you know B type bins it can carry. So, that means it has to travel to 50 bins first and then take this garbage to the landfill site and then return back. So, it can travel along both major and minor roads it has screw capacity of two at a capacity of 20 meter cube.

Finally, comes the smallest of the vehicles it is a auto rickshaw type vehicle seat it carries for this is for collecting garbage from the C type bins and it can collect garbage from 28 pins in one trip. So, that that is again as per the capacity of the vehicle the capacity is 7.5 meter cube required is two and it is usually for the congested areas.

So, as you can see there is no specific system which is suitable for all areas as per my area as per by no road network as per the existing system that is there we have to design our collection system.

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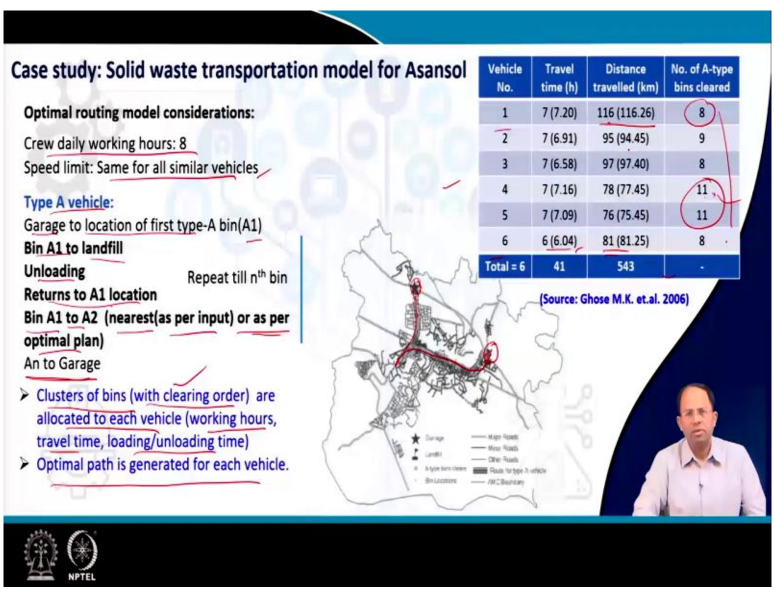

So, how is the optimal routes generated. So, first 8 hours of working is considered. So, 8 working hours means once 8 hours is over that means we have to use another vehicle because beyond which people will not work. So, the drivers will not work the collectors will not work. So, that means within 8 hours one vehicle can collect only a certain amount of garbage.

So, if it is not able to collect from all the bins we have to add another vehicle to the list. So, in that way we have to not only determine the routes for each vehicle but also how many vehicles would be returned required and which vehicle will go to which area. So, speed limit is considered same for all similar vehicles and this speed limit is actually or speed value is utilized to determine the travel time in each link as per the links distance.

So, first designing the roots for type A vehicles the type A vehicles collects from type a type of bins and first it starts from a garage to it goes to the location of the first type A bin and let us assume it is to be a one and from being a one it goes to the landfill because it can carry only one bin at a time it unloads the bin over there then returns to the location of A1 places bin A1 and then travels to A2.

So, bin A1 to A2 and which sequence they may travel either it can go to the nearest one or as per the input of the user he can order the you know the sequence in which he will travel from one bin to another or it could be as per a optimal plan that is based on the location of all these bins we can decide on the sequence in which this particular vehicle will travel from one bin to another.

So, that can also be done as we have done in case of earlier that is there where community bin A and B in the prop in the last lecture we discussed two committee wins in which sequence we will go to which bin. So, based on the overall optimal plan we can also determine that. So, finally A if it keeps on doing this and returning back to the same place and then finally when the A1 AN or the final bin is completed then it can return to the garage but as you can understand there is working hours, travel time and loading unloading time that is required.

So, one vehicle may not be able to go to all the bins. So, a cluster of bins with clearing order that is with a sequence in which mean to go after which that could be based on that optimal plan are allocated to each vehicle. So, this is the one thing and the optimal path is generated for each vehicle. So, as you can see this is the optimal path generated for one of the vehicles this is how it goes and this is how the vehicle.

So, this is the garage location this is where it starts and landfill site is over here and this is how the vehicle travels from different binbins along the way it will pick up and then will go to the lateral side. So, the final result is vehicle number one there are six Vehicles required. So, each vehicle is used for certain time seven hours twenty minutes six hours ninety one minute six hours fifty eight minutes it depends based on the location of the binbins based on what time the last bin ended I may not have adequate time for another bin and so on.

So, you can see that more or less all vehicles are utilized and only the last vehicle is utilized a little bit lesser total distance travel is also similar for most of the vehicles the last vehicle is a little bit less the last two vehicles are less and number of bins cleared are also different. So, you can see that even though this has traveled for larger distance is the number of bins is less. So, because there is distance between these beams as well right.

So, in this case the means may be clustered together. So, that is why more number of bins could be collected. So, or this bins are located near to the landfill site that is why more number of bins are collected. So, if for each condition we will get different set of number of vehicles different routes for each of these vehicles and different time schedules for each of these vehicles.

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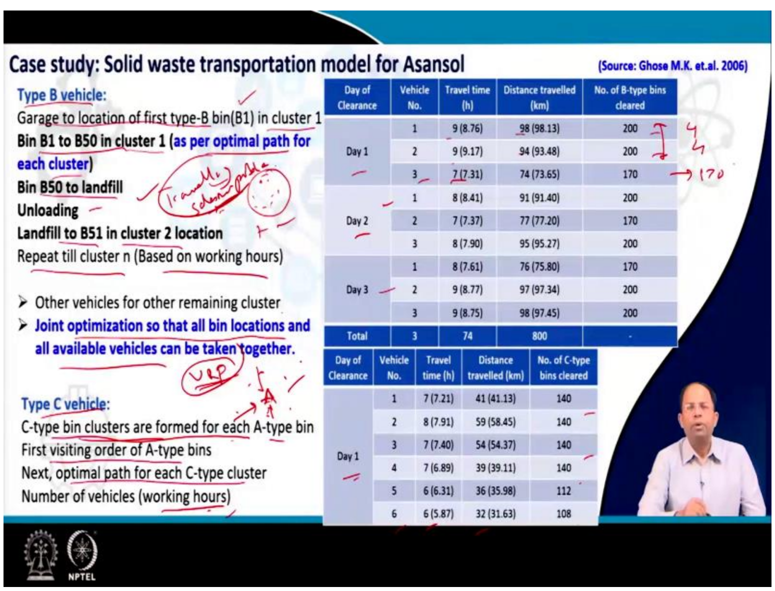

Now, coming to vehicle type B like here I collect the garbage bins from different societies and all and as we discussed it we can go to 50 bins locations and then go to the landfill site. So, first we start from garage to location of first type B bin this let us call it B1 and let us this bin be in cluster one. So, what we are doing is we are creating a cluster of 50 bins.

So, based on their nearness we can determine that in one area this cluster of bin should be taken care by one particular vehicle. So, bin one to bin B fifteen clustered one as per optimal path within each cluster. So, I have 50 locations and the vehicle has to travel from one location to another to each of this fifty using the shortest path and that we have to determine that it is not only the shortest path it is the shortest route what which sequence we will go should I go to bin one or then to bin four then to bin 8 or should I go bin 1 to bin 2 bin 3.

So, it all depends on which sequence is the most optimal. So, so from bin B fifty then it goes to the landfill then it unloads then it again comes back and landfill b51 in cluster 2 then it starts working in the second cluster. So, so we will repeat we will keep on adding classes still based on the working hours other vehicles for other remaining clusters and of course one vehicle cannot complete all the clusters because total build number of this kind of bins is quite a lot.

So, we have to add on other vehicles as well. So, joint optimization. So, that all bin. So, sometimes here what we have discussed in now, that is we are finding the optimal path for moving inside a cluster. So, this is where we use something called a traveling salesman problem it is a called a traveling salesman problem I will discuss that in detail.

Now, this is what exactly what we learned in our previous slide previous lecture where we said that a vehicle starts from a depot goes to two locations in and we have to find the best sequence in which the vehicle should travel and reach the landfill side and again come back to the depot.

So, this only thing is this vehicle can complete one cluster return to the next instead of returning to the depot it returns to the next cluster which may be we can fix it or we can also put in some time within that particular journey and we can say that this vehicle can is made available after a certain time then it could be engaged in another rout. So, it could be a sequence of route for one vehicle as well.

So, that is one the other is we can do we we have the setup all bins in the city we know the capacity of each vehicle and we can do a joint optimization. Where all bin locations and all available vehicles are taken together and using a vehicle routing problem we are bRF VRP and then we can determine instead of a traveling session problem we can use a BRP to determine we can use multiple vehicles multiple routes to determine which are the best suitable solution for this particular area. So, we will explain VRP and TSP subsequently.

So, over here you can see the collection is done in three days every alternate day. So, three vehicles are required in the day one and you can see the time of travel is nine hours for the first two vehicles the last vehicle is little bit less and distance traveled is also computed and number of bins collected is also given.

So, the first two vehicles collect from 200 bins. So, they are able to do four clusters each whereas the last vehicle just needs to go to and collect from 170 bins. So, in day two also similar values could be found out. So, maybe the day two the results are different the day three results are different it depends on the quantity of waste generated and so on. So, similarly for type c bins we use type c Vehicles the C type bin clusters are formed for each A type bin.

So, first for each A type bin because C type bins are usually taken to a type bins. So, for each a type bin we find out which are the C type bins which would come to this particular A type bin. So, that bin clusters are formed using C type bins which are assigned to each a type first visiting order of A type bins first we have to determine which A type bin I should visit first and then next optimal path for each C type to access to be determined.

So, once I decide that I will start with this particular cluster I find the optimal path within the cluster and I put take the waste to the particular A type bin once that cluster is done then I move on to the next cluster till my working hours is expanded. So, it almost same as the last one that was done. So, that here also it is done for three days but I am only showing for day one you can see six vehicles are required travel time for each vehicle distance traveled and number of bins covered by each of these packets. So, this is the final results that we are getting.

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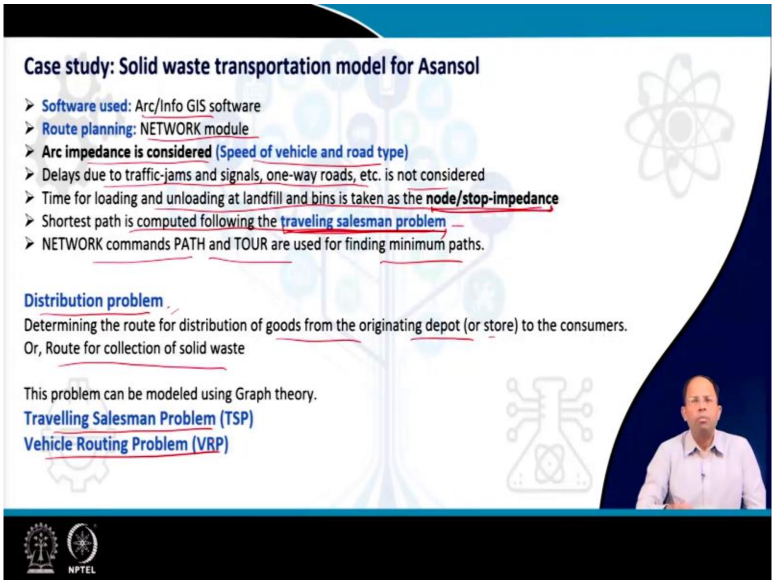

Now, how was all these things computed how was this calculated. So, in this work this authors have used the software Arc Info this is a GS software as you know and the within Arc input there is something called a network module and using this network module you they you can build the route network and then convert it into a this node yeah a link node diagram.

And within that you can do the conduct the network analysis and Arc impedance is considered speed of vehicle and road type delays due to traffic jam signals one-way roads these are all can be considered in the software but here the this study has not considered them time for loading unloading at landfills and bin is taken at the node stop impedance.

So, as we have said that any node can be given some entry and end time and there this is this not stop impedance determines that how much time you spend at that node shortest path is completed following the traveling salesman problem and network command paths path and tour are used for finding minimum paths.

So, traveling session problem computes the shortest route not the shortest path shortest path is determined by dextras but a combination of multiple shortest path in sequence between different points that is the shortest route that is solved using a traveling salesman problem. So, this traveling salesman problem is basically a distribution problem in mathematics it is known as a transportation we call them as distribution problem and where determining the route for distribution of goods from the originating depot or a store to the consumers.

So, that is the starting of the distribution problem or in our case routes for collection of solid waste from different community bins to the landfill site. So, that is the say that is the representation of distribution problem in our country. Now, this problem can be modeled using graph theory same that we discussed in the last lecture and we can use traveling salesman problem or vehicle routing problem to solve this particular here this case.

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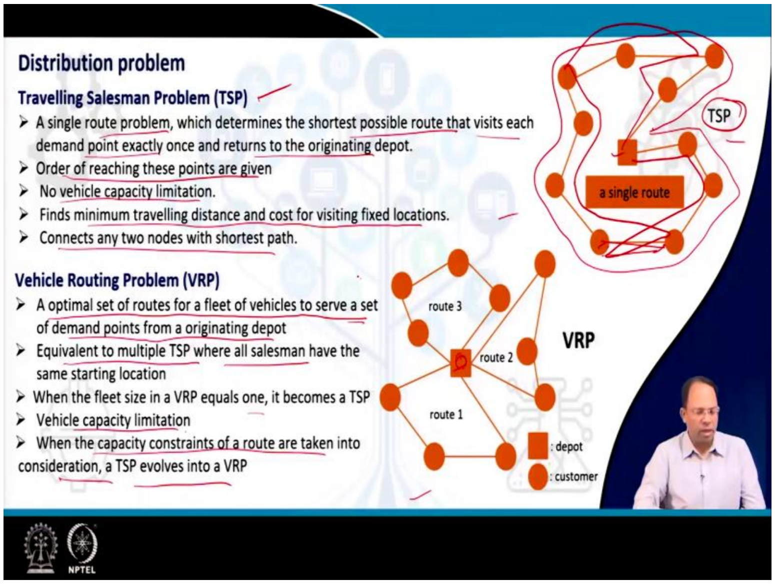

Now, what is the traveling salesman problem, it is a single route problem we determine one route like for example it is the here this is the starting point of the vehicle and we are determining one single route which determines the shortest possible route that visits each demand point exactly once and returns to the originating point.

Over here I have gone via this particular route and they have returned back to this particular you know starting point I could have give instead of going like this I could have gone like this and so on then I could have gone here and then this may be shortest but may not be. So, I do not know which sequence is the most you know gives me the shortest path.

So, a traveling session problem actually determines the sequence in which we should go to each of this and while we go from travel between each of these nodes we use the shortest path between this particular nodes. So, that is determined by dextra's algorithm ordering of reaching these points are given. So, in which sequence we would reach this points that is given number of there is no vehicle capacity limitation is also being considered in TSP because one vehicle has to go and reach all this particular punch.

So, there is no point of vehicle capacity restriction finds minimum traveling distance and cost for visiting fixed locations and connects any two nodes with the shortest path. So, between 82 nodes it is connected by a shortest path. So, that is the traveling salesman problem. Now, what is a vehicle routing problem it is a variant of the traveling salesman problem where a optimal set of routes for a fleet of vehicles to serve a set of demand points from a originating depot.

So, for serving this set of demand points I may say that there is a vehicle capacity restriction one vehicle may not be able to serve all points or the capacity restriction could be in one route of one vehicle may not be able to serve the all points. So, it has to make three journeys or that means it has to go make three conduct three journeys in three route or if the time taken for each route is more than the working hours then in that case I would require more vehicles.

So, that is what the vehicle routing problem determines it determines the optimal set of routes that how many routes needs to be formed for a free for a fleet of vehicles to serve a set of demand points from the originating depot this is equivalent to multiple traveling salesman problem where all salesmen have the same starting location. So, every vehicle is a salesman, it starts from this same point and it goes around and comes back to this particular point.

So, how many vehicles are required depends on the time of start, the time of end and if our one vehicle can serve multiple route that can also happen. When the fleet size in a VRP equals one it becomes a TSP and vehicle capacity limitation is also there that is why when the capacity constraints of a route are taken into consideration our TSP evolves into RPR.

So, anyway we are not doing detailed estimates or calculations or how to solve all this but at least you should have an idea that this could be solved via this kind of algorithms this kind of problems in this particular ways.

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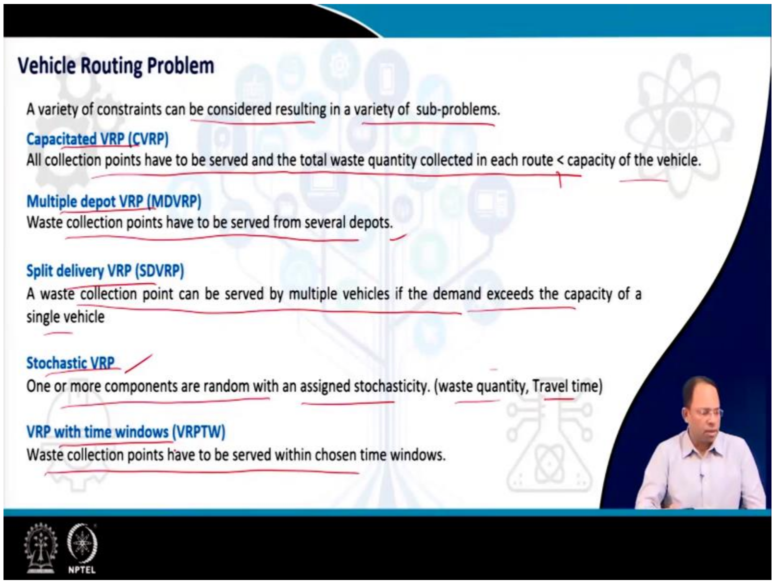

Now, the vehicle routing problem as you can understand that there could be several variants of this vehicle routing problem and this a variety of constraints can be considered resulting in variety of variants or sub problems. Now, in terms of solid waste management these are some of the varieties which we can come across one is called a capacitated VRP where all collection points have to be solved and the total waste quantity collected in each route is lesser than the capacity of the vehicle.

So, this is a capacitated VRP that means the vehicle has been given a capacity. So, it cannot go to more points when till it is capacity is expanded. So, that is the first point then multiple depot VRP that is waste collection points have to be short from several depot that means instead of one depot if I have multiple depot. So, then how do the algorithm adjust itself or how we can solve it.

So, that is a variant of the standard vehicle routing problem then split delivery VRP a waste collection point can be sort by multiple vehicles if demand exceeds the capacity of a single vehicle. So, of course if we have many collection points but some of the correction points you have three or four bins because it is a large collection point like a market and so on.

So, in that case it has to be served by multiple vehicles. So, how do I do the overall allocation of routes for all these vehicles with some points where these are common points where all vehicles will come. So, that has to be the demo then stochastic BRP where one or more components are random with an assigned stochasticity like the waste quantity can vary over time for the same point the waste quantity may not be same every day or the travel time allow a corridor may not be same every day. So, if I introduce this stochasticity or this probability in the estimation then what it means is every day the values are different.

So, my optimization strategy has to consider that. So, that is called a stochastic beard then BRP with time windows which is best collection points have to be served in chosen time index that means when I form the roots there are constants. So, at what time I can reach there. So, this is called a VRP with time windows. So, these are the different vehicles very variants of the vehicle routing problem that could be adopted in waste collection studies.

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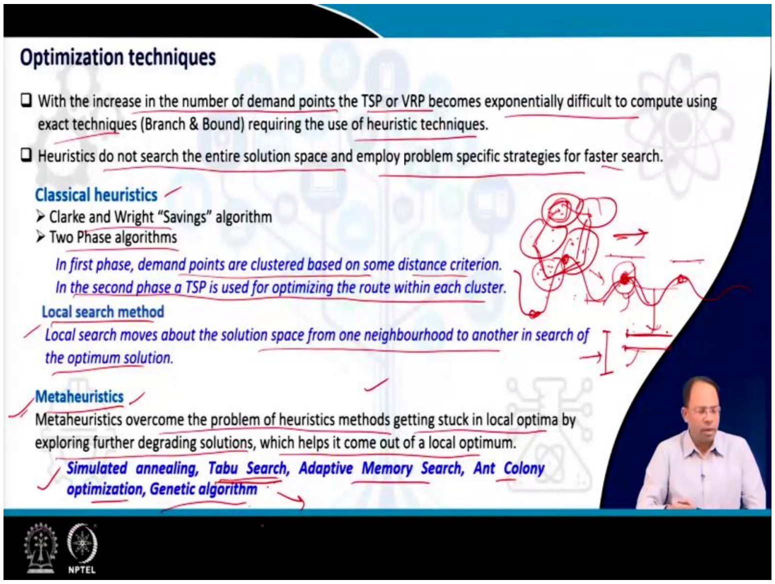

So, as you understand that this is the overall problem but to solve it we require certain techniques or certain optimization techniques because as you can understand there are many route options that are generated but there has to be certain techniques to optimize it.

So, as you understand with increase in the number of demand points like community bin collection points the TSP or VRP becomes exponentially difficult to compute using exact techniques in the first slide we have done exact calculations for each of the options available in front of us and we can easily say that this is the smallest route but when the options become very

very large then exact techniques fails there we required some heuristics you know some certain rules or certain procedures.

So, that we can come to a problem solution at a much more faster phase. So, heuristics do not search the entire solution space but employ problem specific strategies for fastest search. So, that means heuristics are procedures to simplify the search process instead of looking into everything we are based on certain criteria based on certain strategies based on certain system properties we have to determine certain strategies to reduce this search space.

So, we can take certain decisions on that some of the classical heuristics algorithms are Clarke and Wright savings algorithm. Then there is a two phase algorithm or the local search method two phase algorithm is in the first phase the demand points are clustered based on some distance criteria like and in the second phase a TSP is used for optimizer route within each cluster.

So, that means this is a two level problem we break the problem into two parts one is we cluster groups of solid waste management. So, solid waste collection bins. So, within each group we determine the optimal paths like we did earlier with 50 bins type B vehicles we were showing that 50 bins could are route for 50 Europe going to 50 bins has to be formed and then in which sequence we would visit the cluster that is also determined optimally.

So, that is the second layer second you know the second phase of the optimization in first phase we find the optimal route among the cluster in the second we will determine the optimal route between the clusters that means how. So, it is a two level TSP you can say then local search method local search moves about the solution space from one neighborhood to another in search of the optimum solution.

So, problem with local search is we in a particular distribution sometimes some values are high some values are low but problem is if I keep on focusing on a local area then I may get stuck over there and I may not find a higher value in some other zone of the solution. So, anyway. So, these are certain methods but as I said that in local search this problem happens that local search actually you know brings you to some area where you are finding a highest value.

But you are not exploring other areas where there may be a hidden higher you know higher value or a lower value whichever you are searching for. So, that means we can get stuck in some zones of the solution. So, to overcome that meta heuristics are being proposed this overcome the problem of heuristic methods getting stuck in local optima by exploring further degrading solutions which help it to come out of the local optima.

So, I. So, I have a solution you know like this. So, so I am finding this is the minimum cost or this is the maximum cost. So, this is the local solution I am talking about I find that within this area this is the one where I have got the maximum cost. So, I say that this is the most optimal value but in another area of this particular solution space I see this value is even higher than this.

So, I am not able to go over there because I am stuck in this local area based on the strategies I have adopted. So, instead what I if I even though I am finding a high value I can say that I want to change this and move to another area randomly. So, there are several techniques for that one of the technique is like genetic algorithm I find two good solutions I combine these good solutions generate an offspring I take some good routes in this particular solution and this particular solution there is one route there is another route.

So, I take some values from this sequence some values from this sequence and I make a new value then we again change it give some amount of of you know this is known as the offspring and from the offspring we can even do some amount of mutation and change that value and then again start finding better solutions in this direction.

So, in this way we can use genetic algorithm similarly there is taboo search I maintain a list of searches that are there we which we say these are taboo or this we will not search within a certain time and then again we can go back and search in those particular areas. So, there are different ways or ant colony optimization where the way and follow other ends using pheromones. So, similar kind of you know strategies are adopted to determine to find the best solution out in a overall solution space.

So, anyway. So, optimize there is classical heuristics then there are meta heuristics that there are exact methods. So, it all depends on the size of the problem if the problem is very large we have to go and use meta heuristics to arrive at the final solution. So, either you use TSP or a VRP both of them utilizes any one of these algorithms and in many cases like as in ArcGIS software as that particular study has used they use mostly the taboo search method. So, in each software will utilize certain strategies to reach the optimum solutions.

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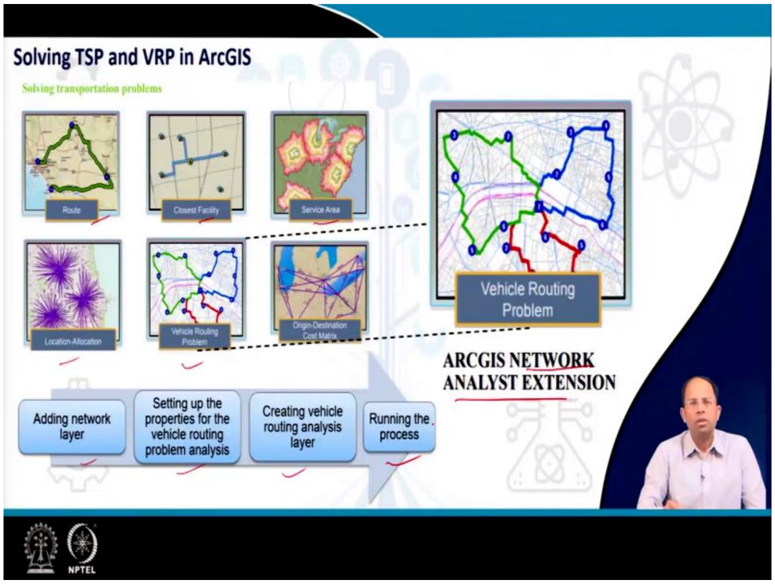

So, coming to the RTX software very quickly I will take you through this software like for example in ArcGIS it is a GIS software where we there is this network analyst part it is one extension or one component of this particular software which you can add and using this you can do this vehicle routing problem and this component is you can do route choice close this is the closest facility service area location allocation.

There are different kind of things you can do which are part of you know transportation analysis one of them is vehicle routing and to do that we have to add a network layer and we have to set up the properties for the vehicle routing problem analysis then create vehicle routing analysis layer and then finally run the process to get our solutions.

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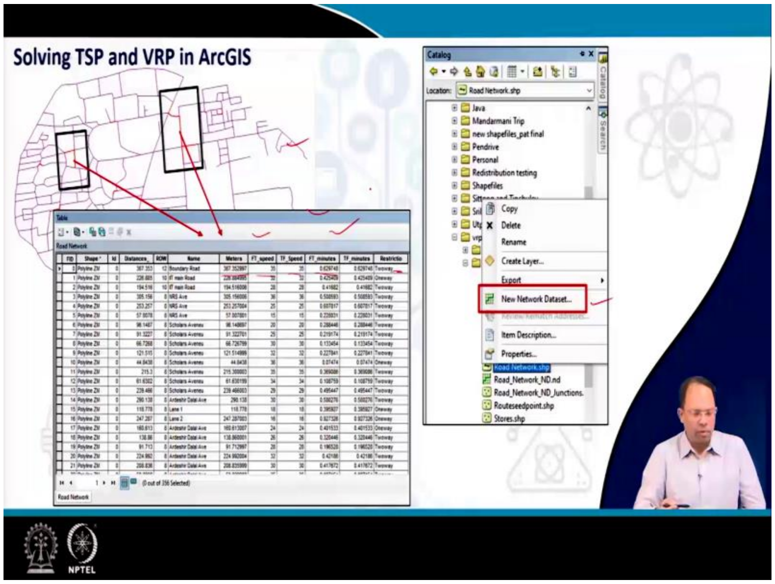

So, as you can see over here this is the map of IIT KGP this is the road network for IIT KGP. So, this is the GIS data for this. So, length of each road segment the speed along that particular road the time taken to travel along those road the restrictions is it a two-way road or a one-way road all these things are given. So, first you have to create a network data set and once then it that is using this particular shape file we have to first create a network data set.

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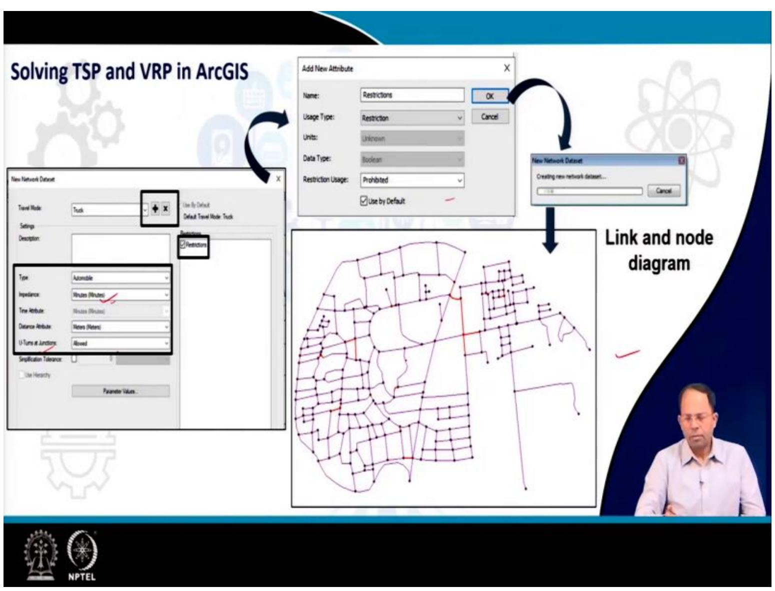

Now, once we create the network data set we have to take the values from though that particular shape file or from that particular table you can say if you are not aware of GIS then from that table we will take the values and we can set that ok in the network in this particular link node diagram finally also the travel time or impedance would be in minutes that means that column in that particular table in the earlier slide we have shown minutes for each link was given.

So, that is taken as the impedance then restrictions U turns are allowed or not. So, all these values are taken up from the table and finally we add for the restrictions we and then finally we create this link node diagram or you can say this is the network layer that we are preparing. So, first converting the GIS layer of road network into a link and node diagram and here also we can add those points for bin locations and all these things as well.

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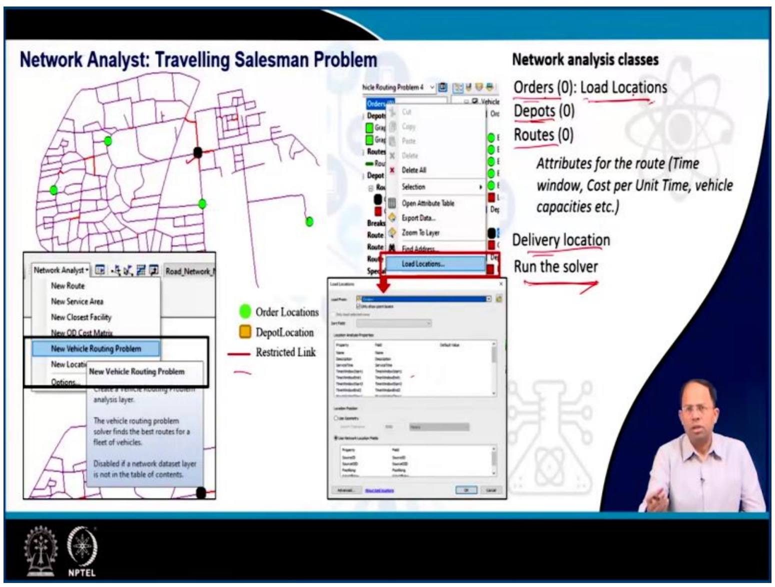

So, once it is the network is prepared in after that we have to start a vehicle routing problem and as we have said that we we can do this with only one vehicle in that case only for one road in that case it would be a TSP and first we have to generate the orders or the points from where you know your community bin should be the depot the route.

So, these are the diff the delivery location and finally we have to run the solver which actually gives us a solution for the route using you know that algorithm that either any form of meta heuristics most probably in jazz they use the taboo search. So, using that algorithm it will find the best possible route. So, we have to run the solver to get the route. Now, for each of the depot for delivery location for the order points order points means the community bins.

So, we have to load the locations of each of these order points as you can see this is the start point these are the order points. So, and then there are some restricted links are also given in red color. So, this that means through this links we cannot travel. So, based on this we have to first create this load locations for each load location there are time windows that could be given the time taken that could be given all these different properties could be added which are properties of those link for those nodes right node impedances and so on.

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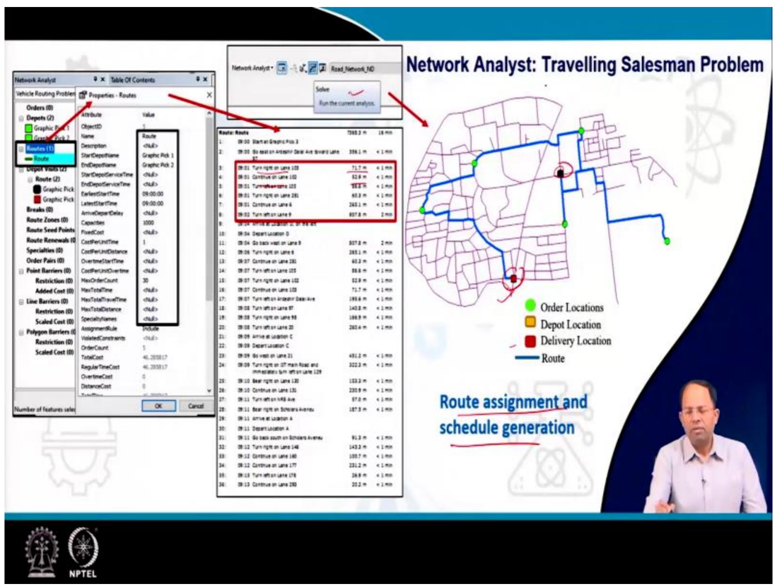

Then finally we have to generate the route. So, as we can in the previous slide we also one of the item was the route in this particular layer and when we have for this route we have to first solve for this route we have to give properties for the route of course like total travel time certain restrictions could be given in terms of start time and time and all this and then we solve it.

And once it is solved you can see the schedule for that route is generated you can see the vehicle that the in which direction the vehicle should go what is the length of the route what is the distance traveled all these things are given and the entire schedule is prepared for solid base collection. So, over here you can see the route assignment and the schedule that is being generated and this is the delivery location the landfill side.

Suppose this is the start depot and these are the points from where one vehicle will collect the garbage and eventually take it over here and this is the shortest path which is being create or the shortest route which is being created and this shortest route is basically a combination of multi people shortest path among this particular collection points and the sequence or the order in which I should go to this particular points gives me the shortest route via that which is done via this traveling salesman problem.

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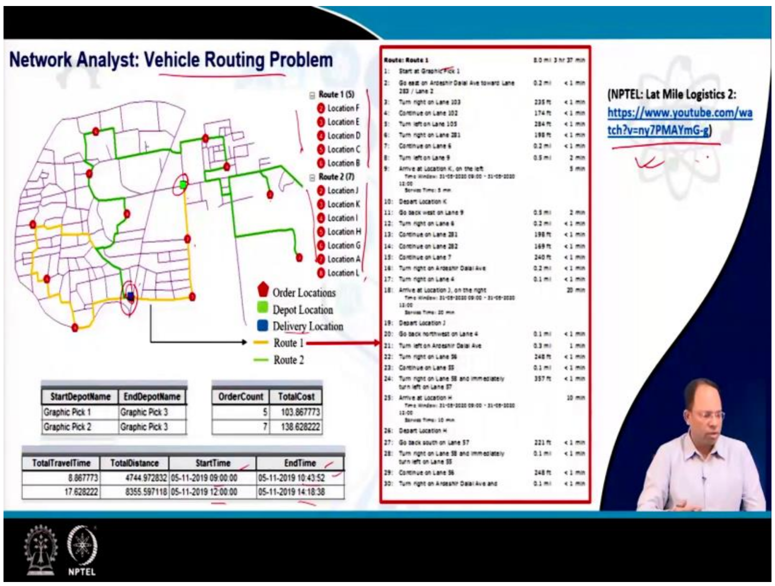

Now, the vehicle routing problem is just a variant of the traveling assessment problem we where we can have multiple routes. Now, multiple routes could be assigned to multiple vehicles or it could one vehicle can also do this multiple routes at different times of the day. So, here also you can see the solution order locations are given in red depot location is over here this is the delivery location of this garbage and we have introduced two routes over here and you can see one green and one yellow route.

So, that means you can say this vehicle will first travel along this particular green road complete it is work and then it will travel along the yellow route or we can say two different Vehicles will be traveling along this path if that time does not permits for one vehicle but in IIT campus the distance are very small. So, one route will start like this the capacity of the vehicle would be expanded within this particular set of you know bin locations and then it has to start another route.

So, which are the optimum routes that this particular solution key and as you can see we have got the values for route 1 and similarly for route 2 also we have got and we can get the total travel time, total travel distance start time and end time for each of this particular route. For example, you can see the start time for the first route is 9 o'clock ends at 10:43, whereas for the start time from the next route is 12 o'clock and ends at 2:18 right. 14:18.

So, that means the same vehicle can be utilized in this particular in sequence first we will collect garbage from these bins by the by the end of this the vehicle will get filled it I will deliver that garbage to that disposal side and I again I will start go to another route I will start with some sequence and as it is given like, for example, this is sequence number one I will go back to the depot from there again I will start one two three, in this way I will form another route and again go back to the disposal side.

So, this is how this vehicle rooting problem is solved using ArcGIS. So, of course you can take a look at my earlier lecture which is a little bit more in detail and I have taken some of the resources from that particular lecture itself. So, this will give you a more thorough idea about this distribution problem and so this is a transportation lecture and you can always practice this in the software itself and then eventually it will become clear.

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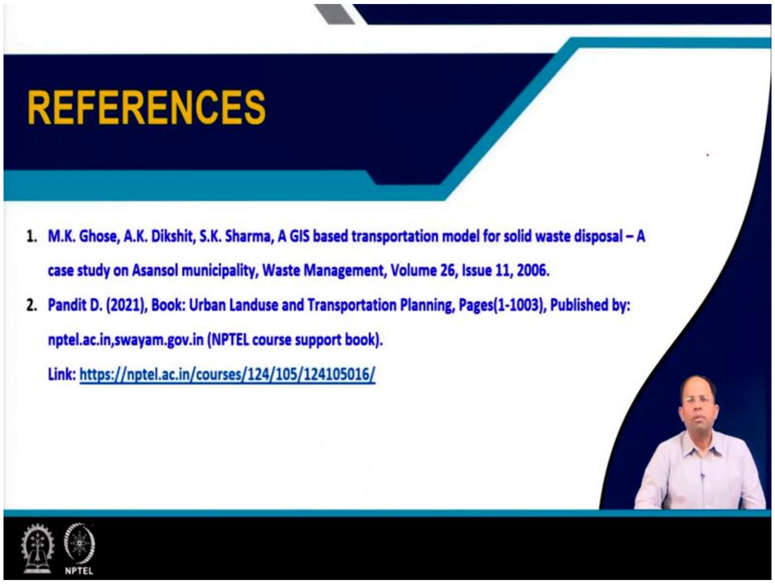

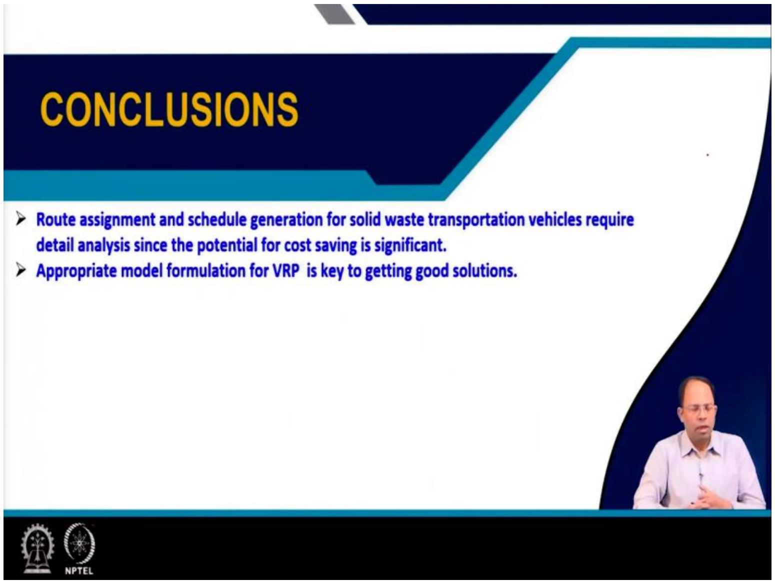

So, these are some of the references you can use. To conclude route assignment and schedule generation for solid waste transportation vehicle requires detailed analysis since the potential for cost saving is significant and appropriate model formulation for VRP is key to getting good solutions. Thank you.