Urban Landuse and Transportation Planning
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Lecture - 55
Last Mile Logistics 2

Welcome back to lecture 55, where the second part of last mile logistics will be completed.

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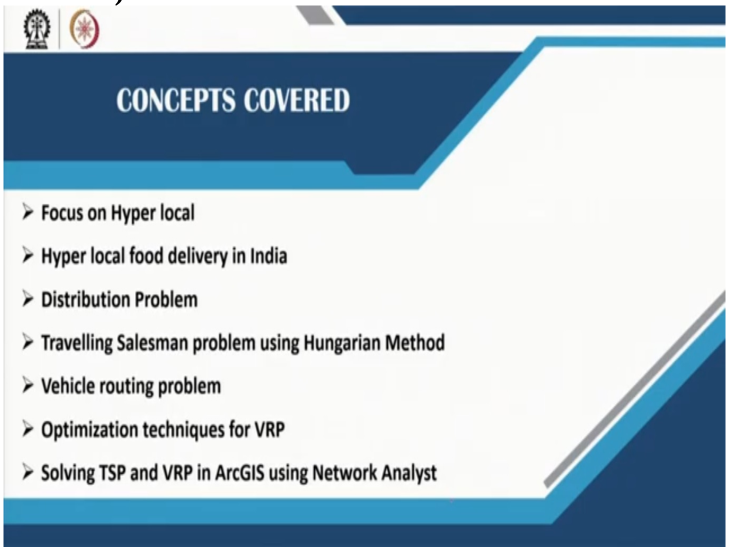

Concepts covered

The different concepts covered in this lecture are hyper local food delivery in India and the distribution problem. Under the distribution problem, travelling salesman problem is solved using the Hungarian method. The vehicle routing problem and the different optimization techniques for solving the VRP are discussed. A demonstration of the Network Analyst tool in ArcGIS, and its applicability in solving the TSP and VRP is given.

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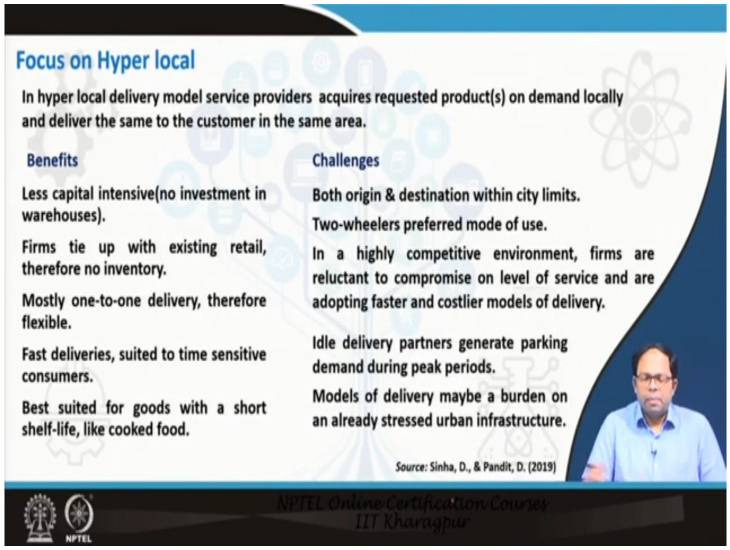

Hyper-local delivery

Hyper-local delivery is a form of last mile logistics where service providers acquire the requested product(s) on demand from local retail stores and deliver the same to the customer. This form of delivery is suited to time sensitive consumers as the deliveries are fast. For the service providers, too, the advantages are many. This delivery model does not entail investment in capital intensive warehouses and distribution centers as deliveries originate at retail stores. As a result the need for inventory management is also eliminated. This can then be suitably scaled up or down according to demand. Deliveries are mostly on-to-one and are suitable for goods with a shorter shelf-life like groceries and cooked food.

Though advantageous for the customer and the delivery service provider, this model creates a novel set of challenges for the urban areas. Due to the highly competitive nature of this business, firms are not willing to compromise on level of service and adopt the costly form of one-to-one delivery. As both the origin and destination of the delivery are within city limits, a large amount of negative externalities, like congestion and emission are generated. The two wheelers used for delivery also create parking demand during off-peak hours and become a burden for the already stressed urban infrastructure.

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Hyper-local food delivery in India

In the hyper-local food delivery system prevalent in India, consumers place orders from a local eatery via aggregators through their online platforms. The radius of this locality is around 3-4 km. As the orders are dynamic, demand cannot be precisely predicted and so, the milk run delivery models fail. Gig workers, called delivery partners, are dispatched when an order is placed. The gig workers are paid per delivery and this pay varies according to the distance travelled per order. Post-assignment, the delivery partner moves to the eatery location from his current location, travelling the first mile in the process. After waiting at the eatery for the order to get prepared, he/she picks it up and travels to the customer location. This distance is called the last mile. After delivery, the partner relocates to an eatery location, which increases his probability of receiving an order. This distance is called the dead mile. The delivery partner gets paid for the first mile, the last mile and the wait time at the eatery but not for the dead mile. The delivery partner bears the cost of the vehicle and the fuel and earns weekly and monthly incentives on his gross earnings. Full time partners have a minimum guaranteed pay, on fulfillment of certain conditions like minimum hours of work and maximum order rejections.

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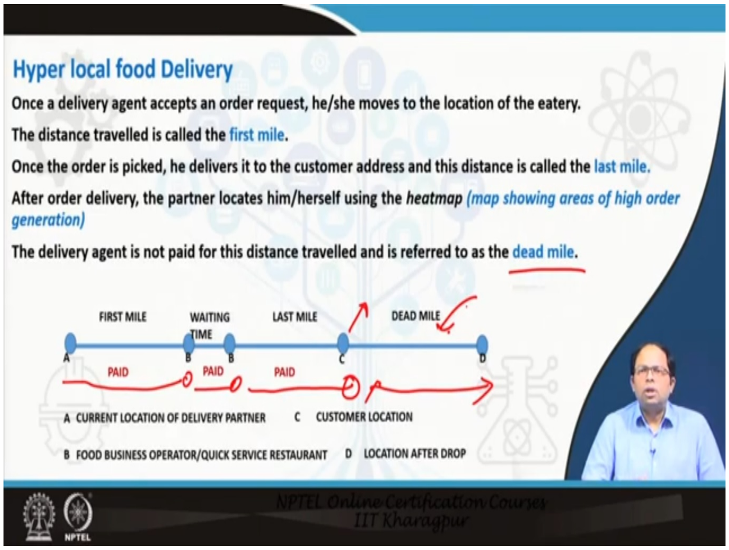

The following part of this lecture deals with the transportation problem and the transshipment problem.

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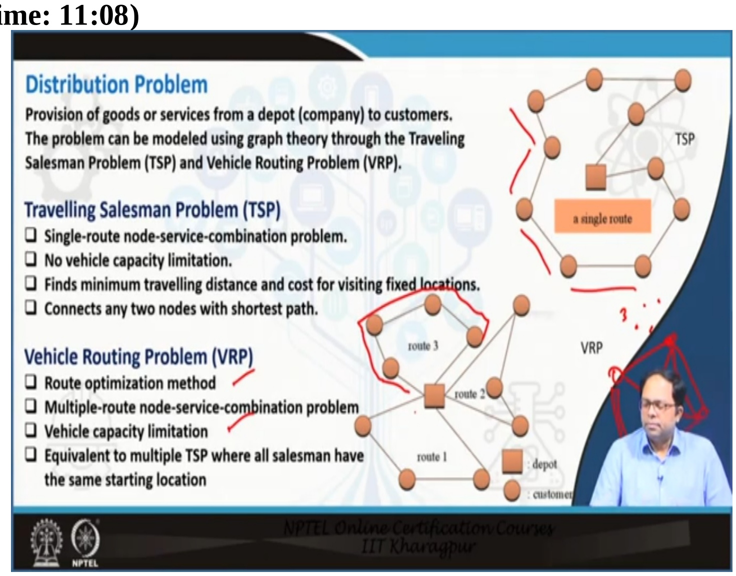

Distribution problem

The problem involves determining the route for distribution of goods from the originating depot (or store) to the consumers. This may involve restocking tours, hyper-local delivery, etc. This problem can be modeled using Graph theory. The two variants of this problem are the Travelling Salesman Problem (TSP) and the Vehicle Routing Problem (VRP). The TSP is a single route problem, which determines the shortest possible route that visits each demand point exactly once and returns to the originating depot. For example if there are three demand points 1, 2 and 3, a TSP will determine the order of traversal of these points from the originating depot 0. The limitation of this problem is that it does not take into consideration the capacity constraints of the vehicle.

The VRP is a variant of the TSP where the goal is to find the optimal set of routes for a fleet of vehicles to serve a set of demand points from a originating depot. Thus, in a VRP multiple vehicles start at the same originating depot, serve a unique set of demand points and return to the origin completing their respective tours. When the fleet size in a VRP equals one, it becomes a TSP. In other words, when the capacity constraints of a route are taken into consideration, a TSP evolves into a VRP.

With the increase in the number of demand points the TSP or VRP becomes exponentially difficult to compute requiring the use of heuristic techniques. These are explained in detail later.

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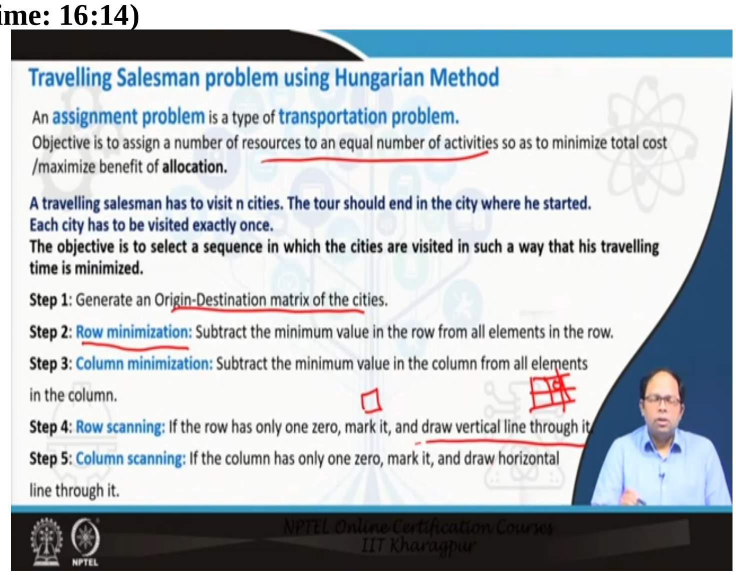

Solving a TSP using Hungarian method

A TSP can be solved using various methods. The Hungarian method is one of them. The Hungarian method can be used for solving assignment problems, which is a subset of the transportation problem. The assignment problem assigns a number of resources to an equal number of activities to minimize the total cost of allocation. In this case the objective will be to match the delivery points to the starting point in sequence and to determine the combination with the shortest route. The steps are enumerated below.

Step 1: Generate an Origin-Destination matrix of the cities.

Step 2: Row minimization: Subtract the minimum value in the row from all elements in the row.

Step 3: Column minimization: Subtract the minimum value in the column from all elements in the column.

Step 4: Row scanning: If the row has only one zero, mark it, and draw vertical line through it.

Step 5: Column scanning: If the column has only one zero, mark it, and draw horizontal line through it.

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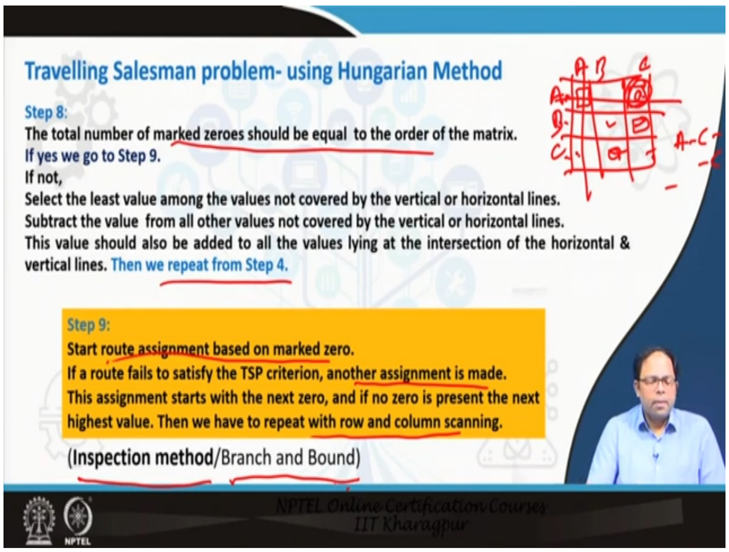

Step 6: The total number of marked zeroes should be equal to the order of the matrix. If yes we go to Step 7.

If not, the least value among the values not covered by the vertical or horizontal lines is selected. Subtract the value from all other values not covered by the vertical or horizontal lines. This value should also be added to all the values lying at the intersection of the horizontal & vertical lines. Then we repeat from Step 4.

Step 7: Start route assignment based on marked zero. If a route fails to satisfy the TSP criterion, another assignment is made. This assignment starts with the next zero, and if no zero is present, the next highest value. Then we have to repeat with row and column scanning.

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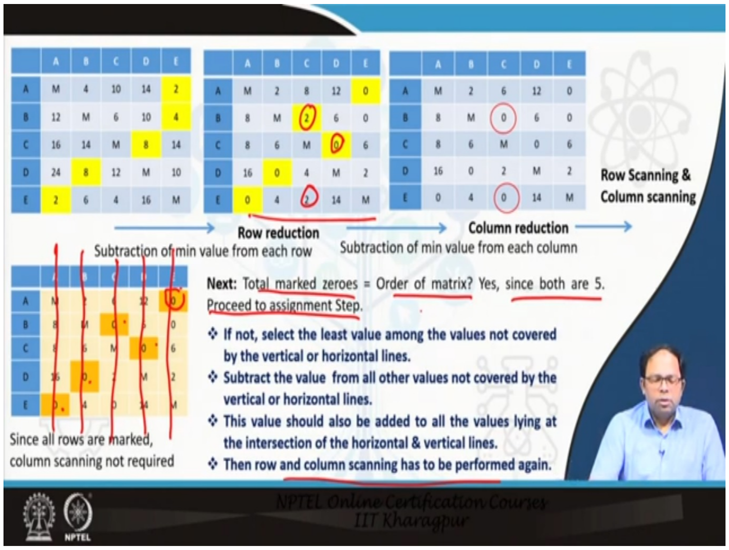

The above steps are explained using an example.

Step1: Refer to the first matrix in the slide for the OD matrix generated.

Step 2: The minimum values in each row are 2, 4, 8, 8, and 2 respectively. These are marked in yellow. These values are subtracted from each corresponding row.

Step 3: In the resultant matrix the minimum values in each column are 0, 0, 2, 0, and 0 respectively. These are marked in yellow. These values are subtracted from each corresponding column.

Step 4: By scanning the rows we mark all the zeroes

Step 5: As all the rows are marked column scanning is not required

Step 6: The total number of marked zeroes are 5, which is equal to the order of the matrix. Therefore, the next step is executed. Otherwise a repetition from step 4 was required.

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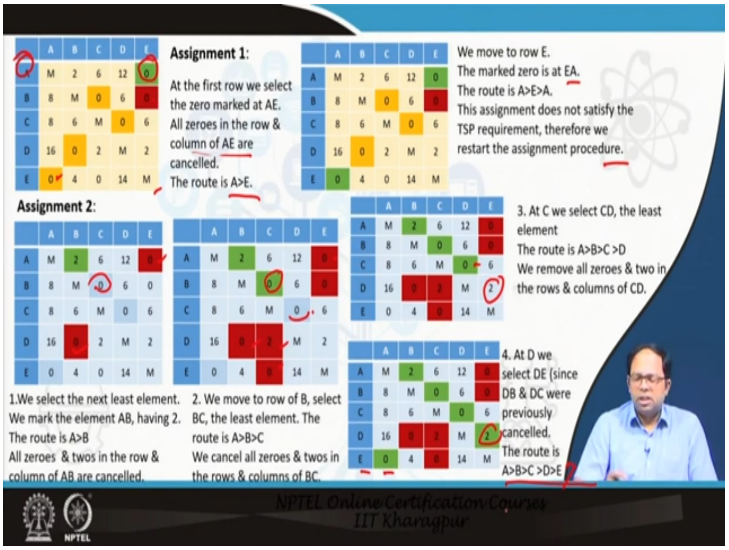

Step 7: This step involves the assignment process.

Step 7a: The zero in the first row is selected, i.e. at AE and all other zeroes in their row and column are cancelled out. The current route is A>E.

Step 7b: At E row, the only zero at EA is selected. The route becomes A>E>A. This route is thus infeasible and route construction is started again.

Step 7c: In the first row, 2, the next minimum element after 0 is selected and all other zeroes and twos in their row and column are cancelled out. The current route is A>B.

Step 7d: At B the minimum element is zero at BC. . The route is A>B>C.

Step 7e: At C we select CD, the least element. The route is A>B>C >D.

Step 7f: At D, DE is selected (since DB & DC were previously cancelled. The route is A>B>C >D>E.

This satisfies the travelling salesman problem and is the optimum route.

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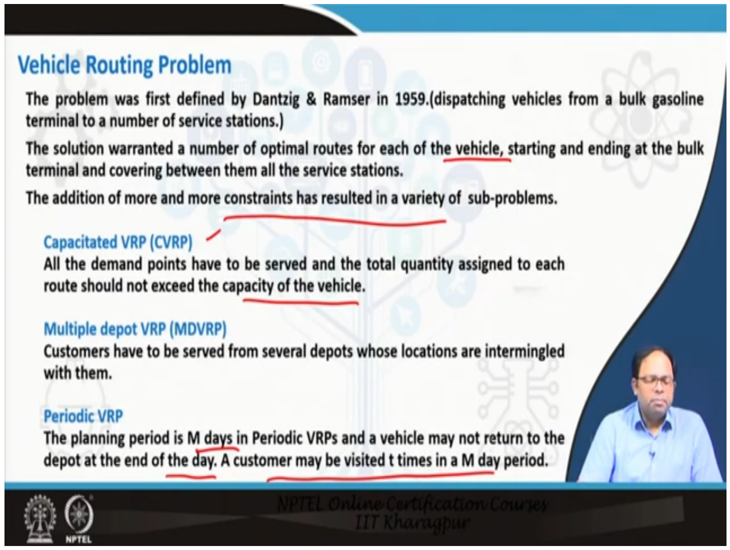

Vehicle Routing Problem

The VRP was first defined by Dantzig and Ramser in 1959. It involved dispatching vehicles from a bulk gasoline terminal to a number of service stations. The solution warranted a number of optimal routes for each of the vehicle, starting and ending at the bulk terminal and covering between them all the service stations. The addition of more and more constraints has resulted in a variety of sub-problems.

In Capacitated VRP (CVRP) all the demand points have to be served and the total quantity assigned to each route should not exceed the capacity of the vehicle.

In Multiple depot VRP (MDVRP) customers have to be served from several depots whose locations are intermingled with them.

In Periodic VRP the planning period is M days and a vehicle may not return to the depot at the end of the day. A customer may be visited t times during the M day period.

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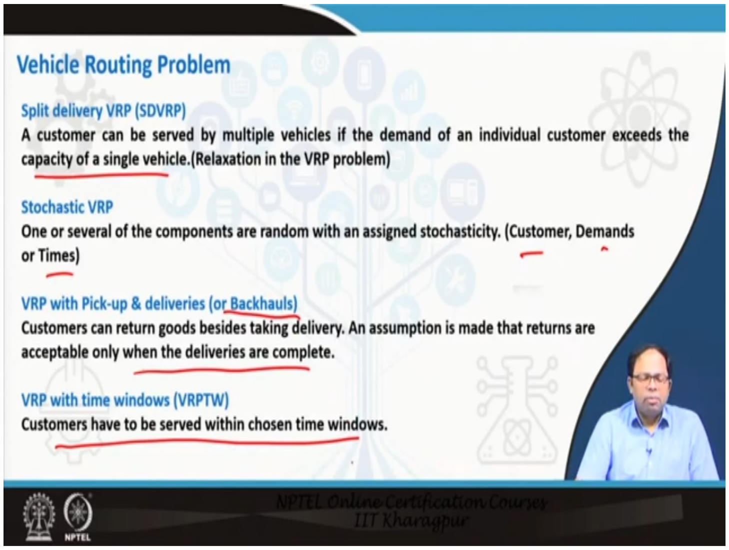

In Split delivery VRP (SDVRP) a customer can be served by multiple vehicles if the demand of an individual customer exceeds the capacity of a single vehicle.

In Stochastic VRP one or several of the components are random with stochasticity assigned to customers, demands or time.

In VRP with Pick-up & deliveries (or Backhauls) customers can return goods besides taking delivery. An assumption is made that returns are acceptable only when the deliveries are complete.

In VRP with time windows (VRPTW) customers have to be served within their chosen time windows.

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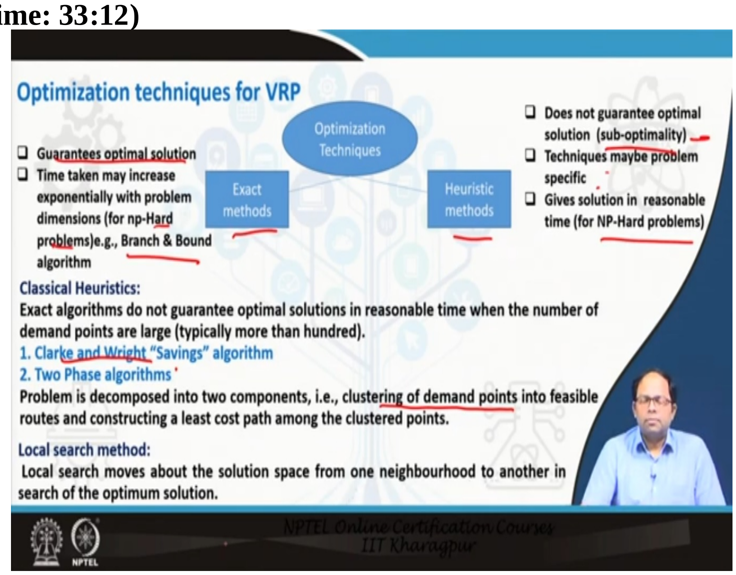

<u>Optimization techniques for VRP</u>

Exact techniques (like the Branch & bound) guarantee optimal solution for a VRP, but with increasing number of nodes becomes exponentially intractable. This calls for the use of heuristic techniques, which are approximate in nature but ensure faster solutions. As a result heuristics result in sub-optimal (near to the exact) solutions. To ensure fast results, heuristics do not search the entire solution space and employ problem specific strategies for faster search.

The Classical heuristic methods involve the Clarke and Wright's Savings algorithm and the two-phase algorithms. The savings algorithm starts by assigning single vehicle route to single customers. A savings is generated when routes are merged. The routes are progressively merged in order of their savings and until vehicle capacity constraints are violated. The two-phase method is a group of algorithms that decompose the problem into two. In the first part, demand points are clustered based on some distance criterion. In the second phase a TSP is used for optimizing the route within each cluster.

And then there is local search method where local search moves about the solution space from one neighborhood to another in such an optimum solution.

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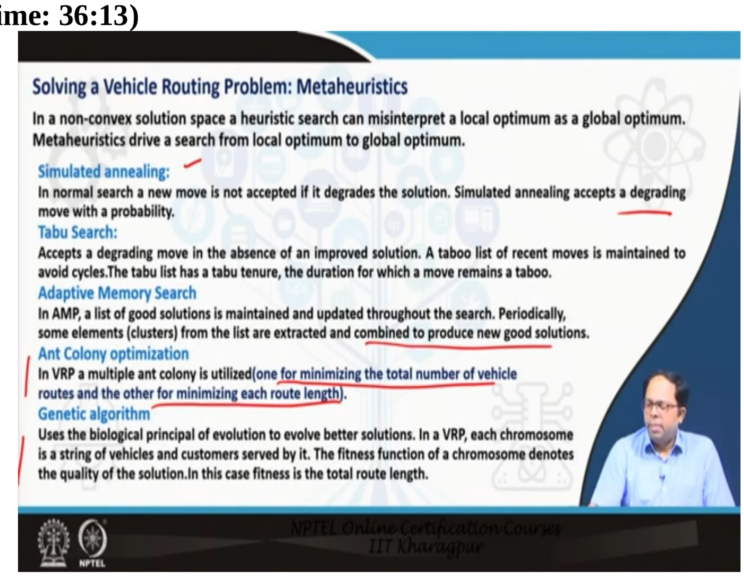

<u>Metaheuristics</u>

Heuristics methods have a tendency of getting stuck in local optima. In a solution space with multiple crests and troughs, a local optima represents the low point of a trough. But the trough may not represent the lowest point when compared to all the other troughs in the solution space. This is the concept of a local optimum. Metaheuristics overcome the problem by exploring even degrading solutions, which helps it come out of a local optimum. Following is a brief discussion of some metaheuristics techniques.

Simulated Annealing is a metaheuristic analogous to the process of heating and cooling a metal. In a large neighbourhood search it drives the solution from a local optimum in search of the global optimum by accepting a new move if it improves the solution but also if it degrades the solution. The acceptance of the degrading solution is based on a probability, which is inversely proportional to a component called temperature. In simulated annealing this temperature is dynamically varied, starting with a very high temperature. The higher temperature ensures the acceptability of low quality starting solutions or random search. The temperature is then progressively reduced to reach the optimum. This process is repeated until the global optimum is reached.

Tabu search is another important metaheuristic that drives local search to a global optimum. The search accepts an improved move and accepts a degrading solution if a better solution is not available. But it maintains a list or array of recent moves that are taboo, as a measure to avoid cycling. The duration for which a move remains taboo is called the tabu-tenure and it can vary over intervals of time. The taboo status can be overridden by an aspiration criterion when a given taboo solution is better than any previous one.

In the Adaptive Memory Procedure, a list of good solutions is maintained and updated throughout the search. Periodically, some elements from the list are extracted and combined to produce new good solutions. The elements extracted are generally clusters and the resulting combination may be a partial solution. A construction heuristic is then utilized to construct a feasible solution.

Ant Colony Optimization is a metaheuristic based on the behaviour of foraging ants. An ant seeking food is guided by the pheromone trail of preceding ants. Stronger the pheromone, higher is the percentage of ants following the trail. In a situation where two alternative paths lead to a point, the shortest route will have a higher pheromone trail, as a consequence of more ants moving per unit time. Subsequently, an increasingly higher percentage of ants will prefer the shorter route till all the ants move to the shorter route. This behaviour is utilized in finding the best path on a weighted graph. In VRP a multiple ant colony is utilized, one for minimizing the total number of vehicle routes and the other for minimizing each route.

Genetic Algorithms use the biological principal of evolution to evolve better solution from a number of starting solutions called the population. A population consists of chromosomes, where each chromosome is a string of vehicles and customers served by it. At each iteration, chromosomes are selected on the basis of a fitness function, the fitness function representing the quality of the solution. The selected chromosomes then undergo a process of crossover, where attributes from the solutions are recombined to form a new generation of solutions. Associated with each iteration is a probability of mutation, wherein the chromosomes undergo random changes. Continuous iteration of the selection, crossover and mutation thus result in a completely new population replacing the older ones. The process is repeated until some convergence criterion is met

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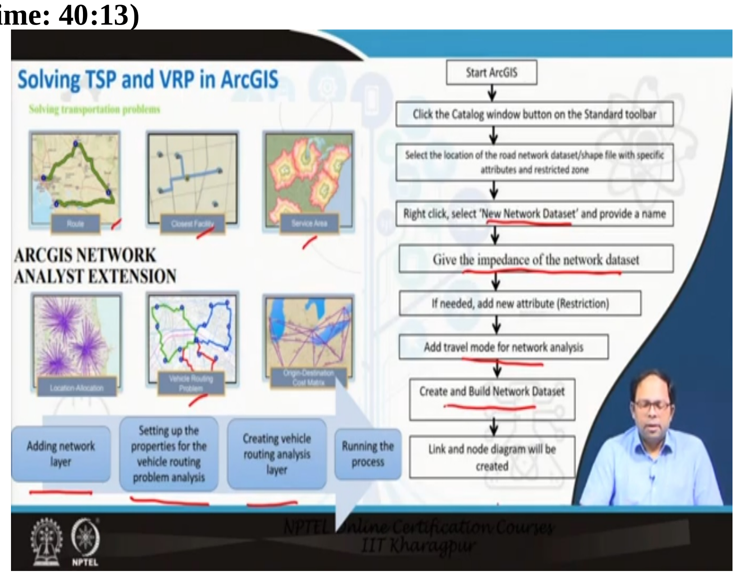

Solving TSP and VRP in ArcGIS

The Network Analyst tool of ArcGIS can solve the following transportation problems:

- Find the shortest route between two points
- Find the closest facility for a set of points
- The location-allocation problem
- The Vehicle routing problem

A link-node diagram needs to be created before any analysis is carried out. The following are the broad steps to create a link-node diagram:

1. After starting ArcGIS, click the Catalog window button on the Standard toolbar
2. Select the location of the road network dataset/shapefile with specific attributes and restriced zone
3. Right click, select ‘New Network Dataset’ and provide a name
4. Give the impedance of the network dataset
5. If needed, add new attribute (Restriction)

6. Add travel mode for network analysis
7. Create and Build Network Dataset
8. Link-node diagram will be created

The impedances can be travel time, travel cost, and so on.

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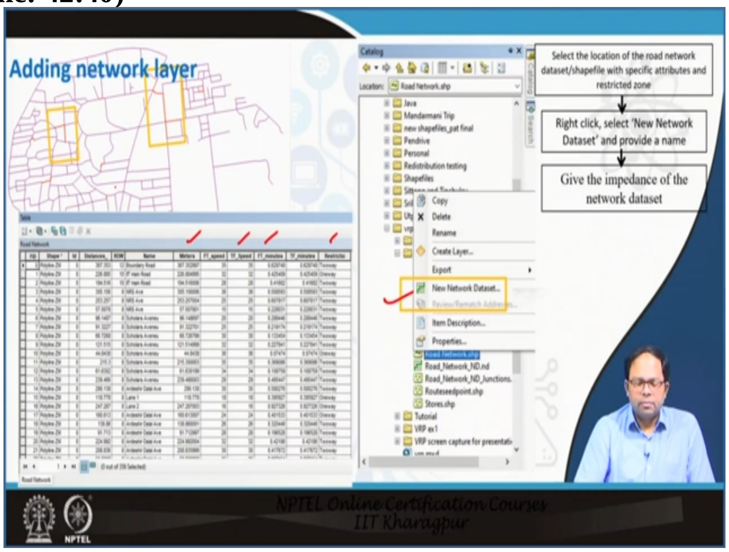

The example shows a map of IIT KGP campus. In the shape file, one can modify the different parameters, like the length of the road, the speed along the road, the total travel time in minutes and other restrictions like one-way travel, and so on. The parameters of each individual link can be changed as well.

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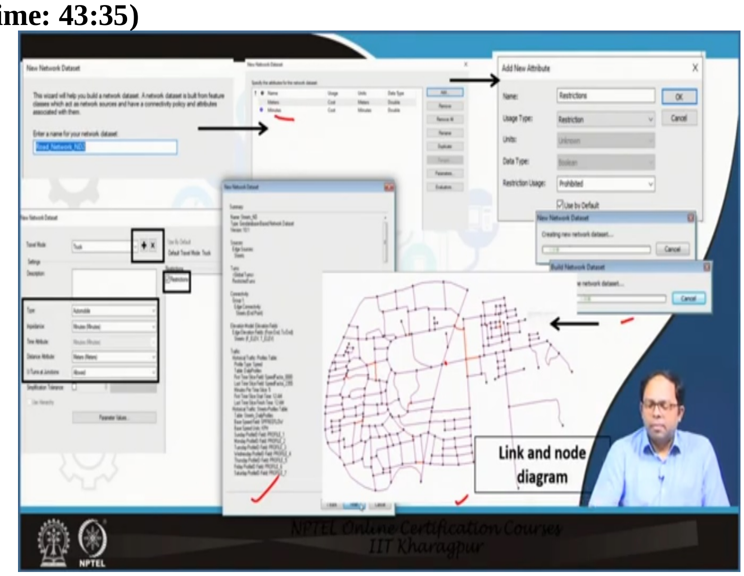

In the impedance, new attributes like the cost (in minutes and meters) are added.

The distances are in meters and u turns are allowed. When the creation of the new dataset is over, the link-node diagrams are obtained.

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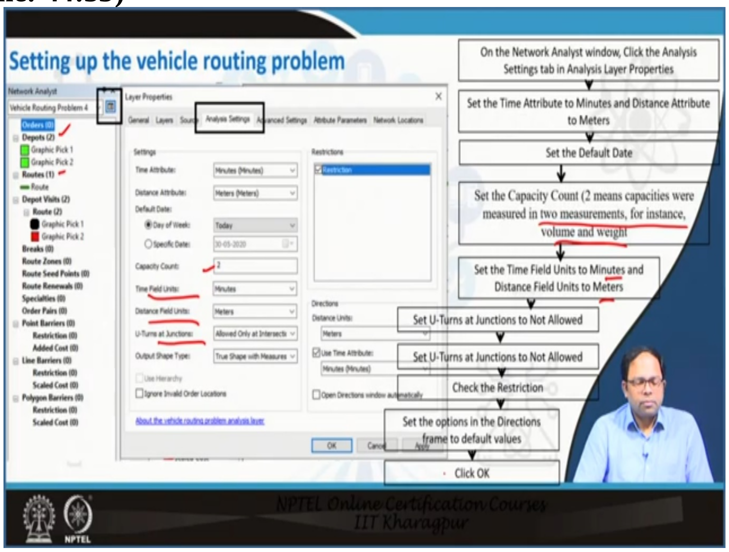

<u>Setting up the TSP</u>

In the network analyst extension, one can select the type of analysis. The steps are as follows:

1. Right click Orders (0) and choose Load Locations. 12 order locations have been selected
2. Select location file, set the appropriate fields in the Location Analysis Properties
3. Right click Depots (0) and choose Load Locations. 2 depot locations have been selected
4. Select location file, set the appropriate fields in the Location Analysis Properties
5. Right-click Routes (0) and choose Add Item. 2 routes have been selected
6. In the Properties window for a route, specify attributes for the route such as Time window, Cost per Unit Time, vehicle capacities etc.
7. Select two different time windows for two different routes
8. Select delivery location

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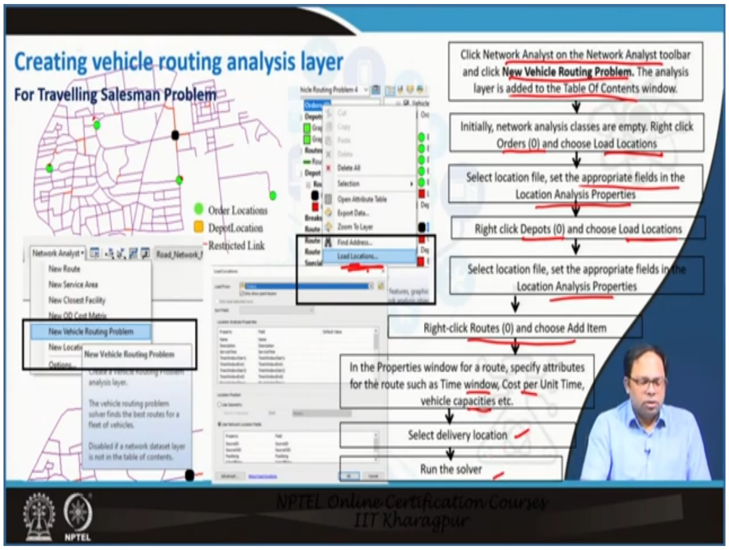

Once everything is setup, the ‘Solve’ button on the network extension window is clicked

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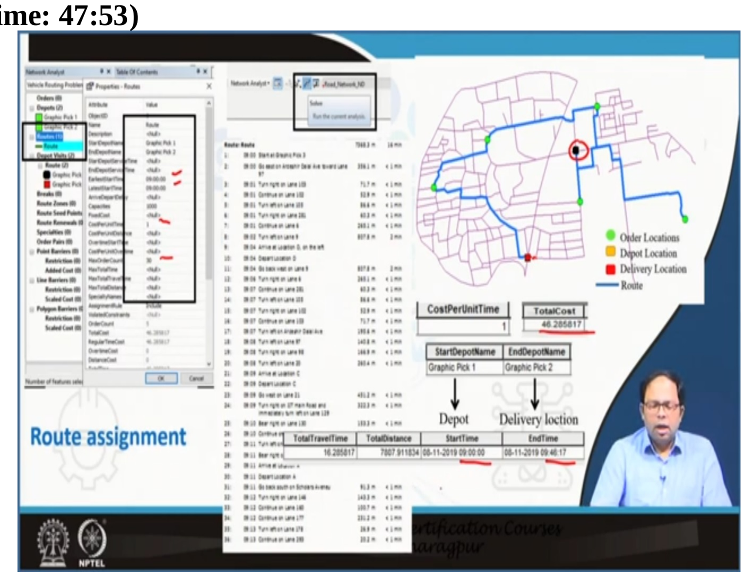

The completed route assignment can be referred to in the slide. The total time taken to complete the route is 46 minutes. Different properties can be set for the route like earliest start time, latest start time, maximum order count, cost per unit time, etc.

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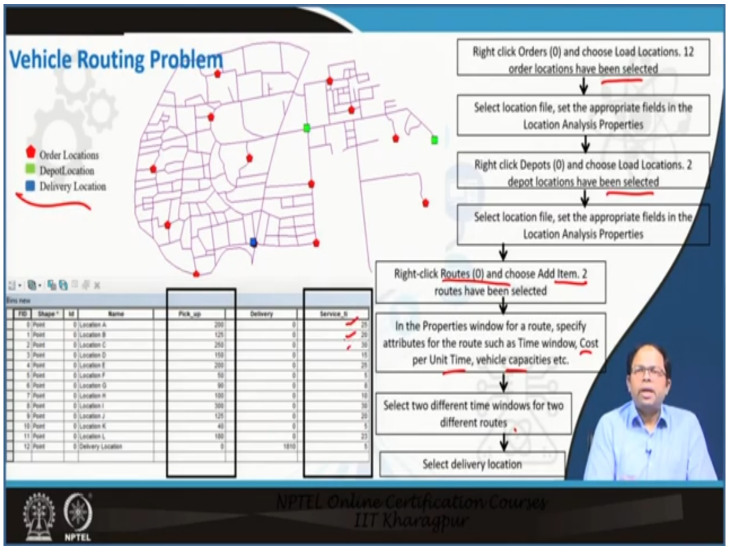

Setting up the VRP

For the VRP most of the settings remain the same, but instead of one, multiple routes can be added. Multiple routes can have multiple time windows and multiple start times. With multiple start times the same vehicle can service the different routes.

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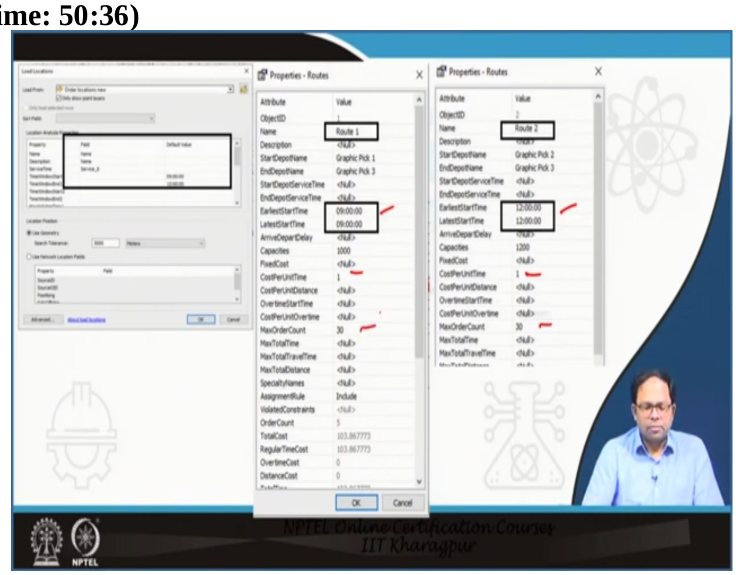

The slide refers to the solution for 2 separate routes, with start times at 9'o clock and 12'o clock, as a result of which the vehicle can consecutively service the two routes.

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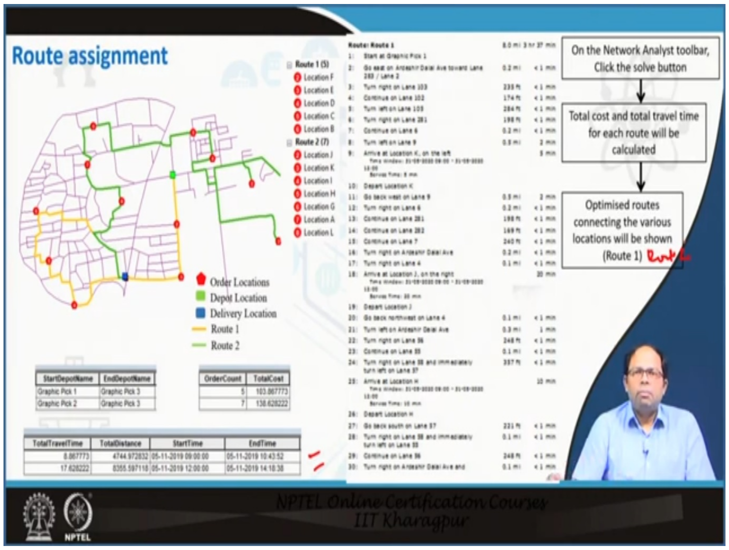

So this is the final solution where green shows vehicle the route taken by one vehicle and yellow shows the route taken by another vehicle and that we have got solutions for 2 routes and one route take around 43 starts around 9 ends at 10 43 another one starts at 12 ends at 2 o clock at 14 18. So, 2 hours it takes 2 hours 18 minutes. So on the network analysis toolbar, we can again use the solve button, total cost, total travel time for each road will be, calculated.

Optimized route connecting the various locations will be shown, so for both route 1 and route 2. So, this is how we can solve the VRP problem as well.

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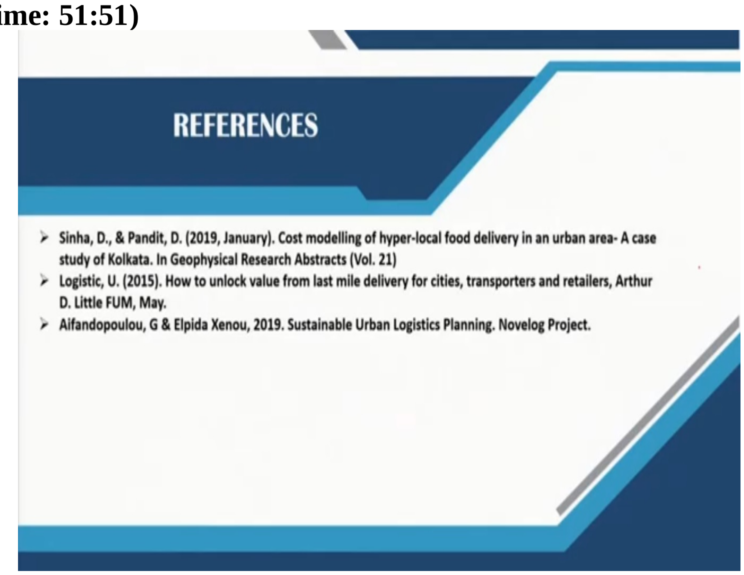

Some of the references are listed in the above slide.

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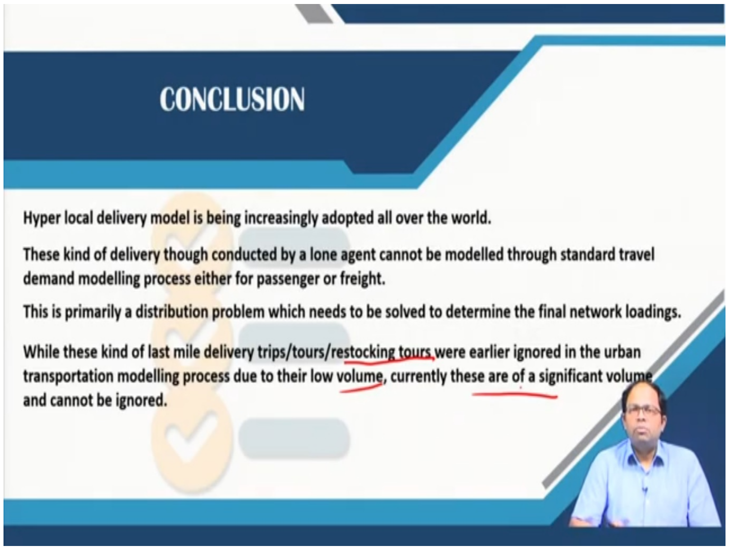

Conclusion

Hyper-local delivery model is being increasingly adopted all over the world. This kind of delivery though conducted by a lone agent cannot be modeled through standard travel demand modeling process either for passenger or freight. This is primarily a distribution problem which needs to be solved to determine the final network loadings. While this kind of last mile delivery trips, tours or restocking tours were earlier ignored in urban transportation modeling process, due to their low volume, currently these are of significant volume and cannot be ignored. So we need to gradually incorporate this kind of analysis to determine freight movement in an urban area.