Urban Transportation Planning
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Module No. # 05
Lecture No. # 23
Trip Distribution Analysis Contd

This is lecture 23 on Urban Transportation Planning; the discussion on Trip Distribution Analysis will be continued in this lecture. Before we proceed further, let us briefly recollect what we did in the previous lecture, you may recall we tried to understand the application of the gravity model with a numerical example in the previous class. On completion of the problem, we discussed about the calibration of gravity model, and as you may recall, calibration of gravity model means determining the parameter value related to F i j, the friction factor.

And when we discussed about the different forms in which F i j can be expressed. We found that F i j can be expressed as a function of travel time, because normally, trip distribution is done using segmented data based on mode used for travel as well as based on trip purpose.

So, once use segment data based on more, the travel time is going to remain a constant, travel cost is going to be a constant, because it is more specific right and other related factors like comfort, convenience, level of safety, and all these factors will remain unchanged, so that is how we felt, it is appropriate to express F i j as a function of T i j travel time. We also discussed about travel distance as a substitute for travel time and understood that it is not appropriate under urban condition to substitute travel distance for travel time, because of variations in the characteristics of the road, network and related factors.

And finally, we discussed about the calibration procedure recommended by BPR, Bureau of Public Roads USA, as per BPR method we assume different functional forms for F i j based on the distance of travel. We segment the travel data based on distance as travel involving, travel time off, or travel distance of certain segment. If you segment the data based on travel time, you can say all trips involving travel time between 0 and 5 minutes, then all trips involving travel time between 5 and 10 minutes and so on right. And then, we develop trip length frequency distribution curve, both for model calibrated value as well as field observed value, and then compare both the trip length frequency distribution curves for matching. If the curves are not matching, we just modify the value of F i j using an appropriate modification procedure and continue the process until there is a reasonable match between the true two two trip length distributions curves right, so that is how we do the calibration as per BPR method right.

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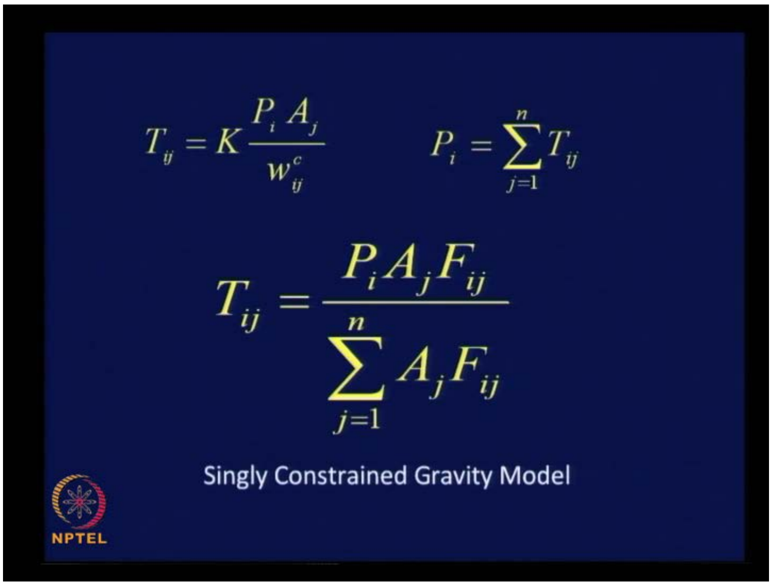

And if you look at the basic structure of the gravity model itself, you may recall this was the basic structure we initially adopted; T i j to be equal to K times P i A j whole divided by W i j raised to power c, this is simply the replication of the equation related to Newton's law of gravitation. We have replaced m 1 and m 2 by P i and A j right, r squared in the denominator is replaced with W i j raised to power c, K is proportionality constant as we had in the earlier equation also, and we modify this equation by introducing a constraint related to trip reduction.

Since, we know P i is equal to sigma j is equal to 1 to n T i j, we introduce this constraint into this basic equation and finally obtained this formulation of gravity model, T i j is P i A j F i j divided by sigma j is to equal to 1 to n A j F i, this is a very simple formulation of gravity model, without consideration to the zone to zone adjacent factor which is K i j. And you, we need to understand that, we have introduced one constraint here, namely P i to be equal to sigma j is equal to 1 to n T i j to get the final equation for the gravity model, so rightly we can call this gravity model as singly constrained gravity model.

What would we do with the other constraint related to trip attraction A j, we satisfy that constraint by iterative process, when we distributed the trips. You may recall we did several iterations to adjust the cell values along each column to be exactly equal to the attraction values right. Finally, we need to satisfy both the constraints related to P i and A j right, but here the model formulation itself has inbuilt constraint which is only one constraint that is why, it is called as singly constrained gravity model, the other constraint is taken care of while we actually distribute the trips.

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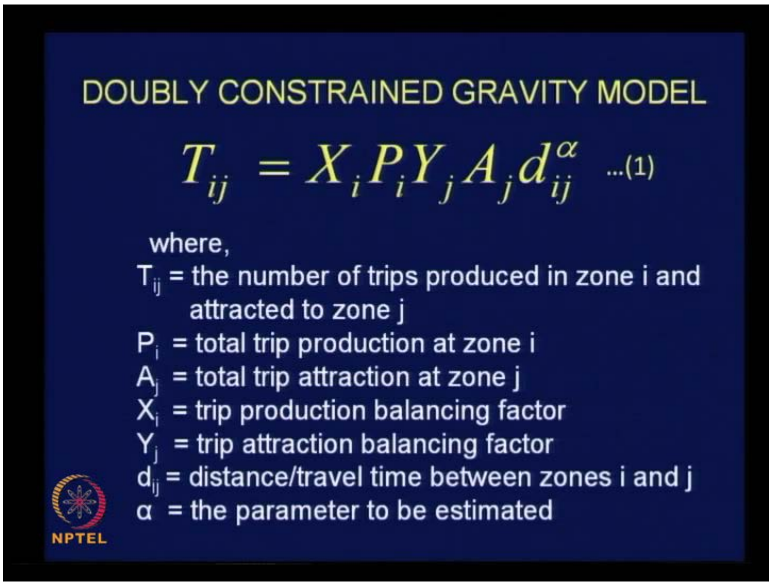

And it is possible to incorporate both the constraint at the initial stage itself and straight away do the distributions process without any iterative procedure involved in getting the trip distribution values, such a model is named as doubly constrained gravity model.

Because, both the constraints are put into the model formulation at the beginning itself, and this the general formulation of the model and the explanation for the notations used are given here, T i j as usual is a number of trips produced in zone i and attracted to zone j and P i total trip production at zone i, A j total trip attraction at zone j, X i is trip production balancing factor. We need to balance trip production such a way that there is no distortion and the trip production values of each of the zones after distribution, so that is taken care of initially. And Y j is trip attraction balancing factor to take care of the constraint that trip attraction of each of the zones is not changed after we distribute the trips, and d i j is a distance or travel time between zones i and j, mostly travel time as we have discussed and alpha, the parameter to be estimated right, this a very general formulation of doubly constrained gravity model.

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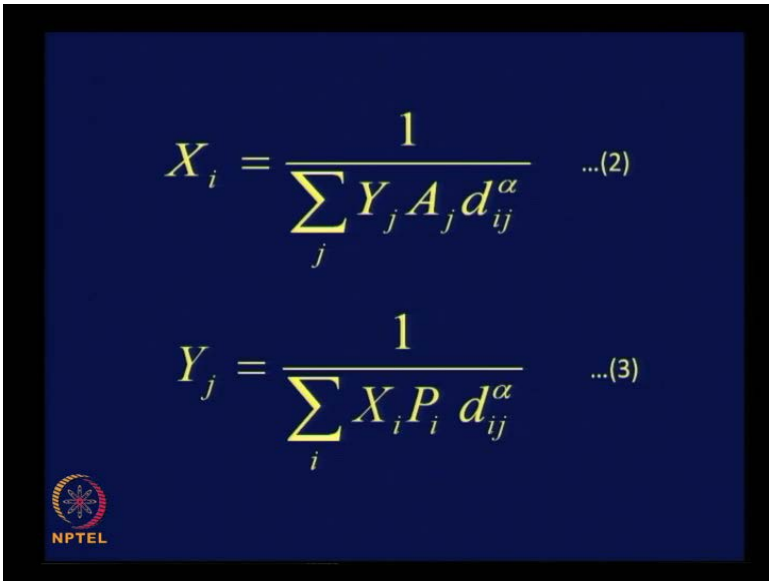

And X i and Y j can be returned as follows, X i is written as 1 by sigma j equal to 1 to n Y j A j d i j raised to power alpha and and Y j is written as 1 by sigma i is equal to 1 to n X i P i d i j raised to power alpha. So, we have the formulations for X i and Y j and we have the general formulation of the gravity model involving X i and Y j. Now, how to go about substituting the known values and getting the value of d i j, trip distribution between zones i and j, this is the question.

Please note that equation 2 involves Y j and equation 3 involves X i right, we are trying to express X i in terms of Y j and then Y j using X i right, once you change the value of Y j, X i will get altered, when once you change X i it will on effect on Y j right.

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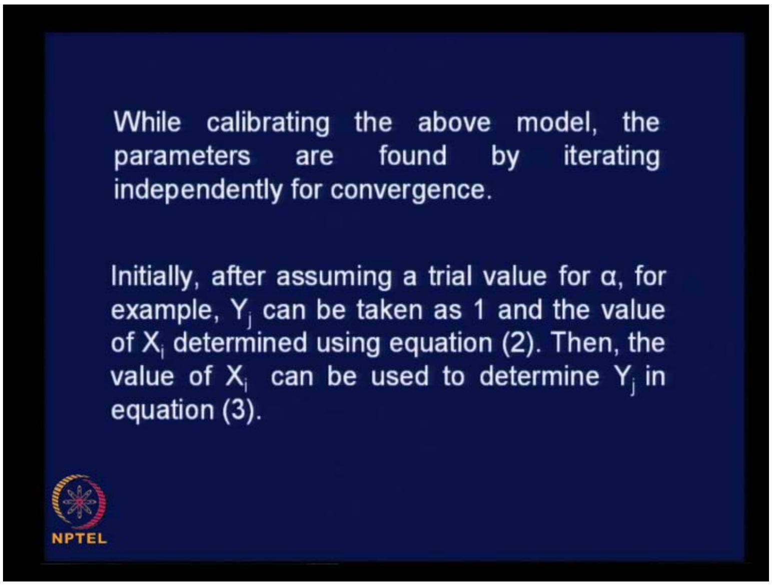

And the procedure followed in the analysis is as follows, while we just calibrate the doubly constrained gravity model, the parameters are found by iterating independently for convergence. First, we take the equations for X i and Y j right, iteratively see that there is no change when we repeatedly calculate the values of X i and Y j so that there is A stabilization that means, the two constraints are taken care of initially, and then substitute back the values of X i and Y j in the parent equation.

This is what we do, initially after assuming a trial value for alpha, alpha is the parameter to be estimated, d i j raise to power alpha. For example, Y j can be taken as 1; you assume some trial value for alpha, that is one step. Then assume initially for convenience Y j to be just unitym some value you can take, and the value of X i is determined using the earlier equation or using equation 2, then the value of X i can be substituted right to get the value of Y j using equation 3 clear.

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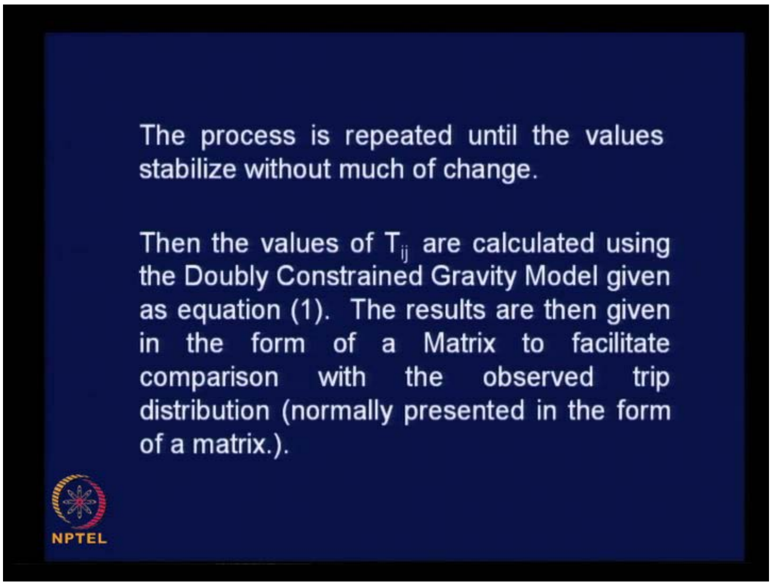

And this process is repeated until the values stabilize without much of change, when you repeatedly substitute for X i and Y j, you will find that at some point of time there is no change at all, it is stabilizing, then those values of X i and Y j are fit for substitution in the parent equation to get the value of T i j.

Then the values of T i j are calculated using the doubly constrained gravity module given as equation 1, the results are then given in the form of a matrix as we normally do, to facilitate comparison with the observed trip distribution, which is also normally given in the form of a matrix. So, we are going to have two matrixes, one based on gravity model and the other one based on the field observed data right, have two matrixes and we have to compare two matrixes for matching, so that is the calibration process.

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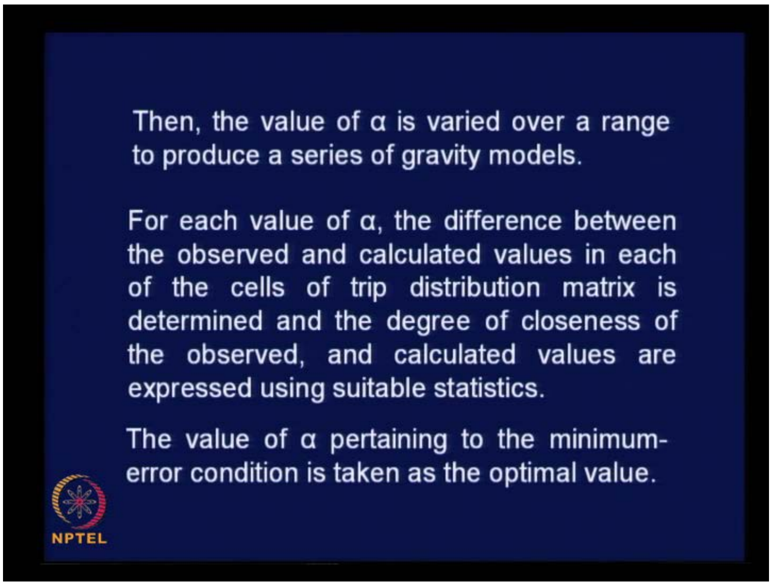

Then, the value of alpha is varied, see this process is based on one initial value of alpha that we assume right, and we are not sure whether that alpha is perfect or representative of the field condition. So, it is better to have a set of values of alpha and then for each case, you just compare your model simulated and field observed matrices and then choose the one or choose the value of alpha which gives a least error in matching of the two matrixes.

That is why, we need to have more values of alpha and do the same iterative process with each values of alpha range to produce a series of gravity models right. For each value of alpha, the difference between the observed and calculated values in each of the cells of the trip distribution matrix is determined and the degree of closeness of the observed and calculated values is expressed using suitable statistics. Please note, calculated values as well as observed values in each of the cells of trip distribution matrix is compared and a variation is determined.

Cell 1 1, in gravity model matrix and corresponding cell in field observed matrix compare both the numbers find the difference. So, like that you compare cell by cell of the two matrices and then get some indication of the match, level of match of the two matrixes. And there are statistical procedures available to get the degree or level of match of two even sets of data. Obviously, the value of alpha pertaining to the minimum error condition is taken as optimal value right.

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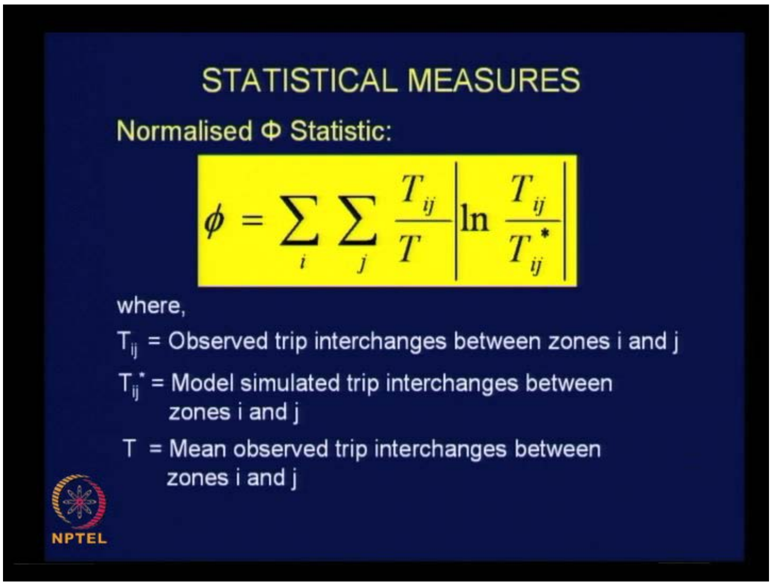

And these are the statistical measures used for comparison of the two matrixes, I am not going to give the basic theoretical background or the proof of these formulae, I will be just giving the result, it is up to you to refer a suitable book and try to understand the theoretical background as well as the related proof. There is one statistic named normalized a phi statistic, and this is the formula to calculate the value of phi, where T i j as you know is equal to observed trip interchanges between zones i and j, observed values as you observe in the field, T star i j model simulated trip interchanges between zones i and j right.

So, T i j values you pick from the matrix that will develop based on observed data, and T star i j values you pick from the matrix that is developed based on your gravity model result right. And T is a mean observed trip interchanges between zones i and j, mean of all the observed values that you can easily calculate, that is what is given here as T.

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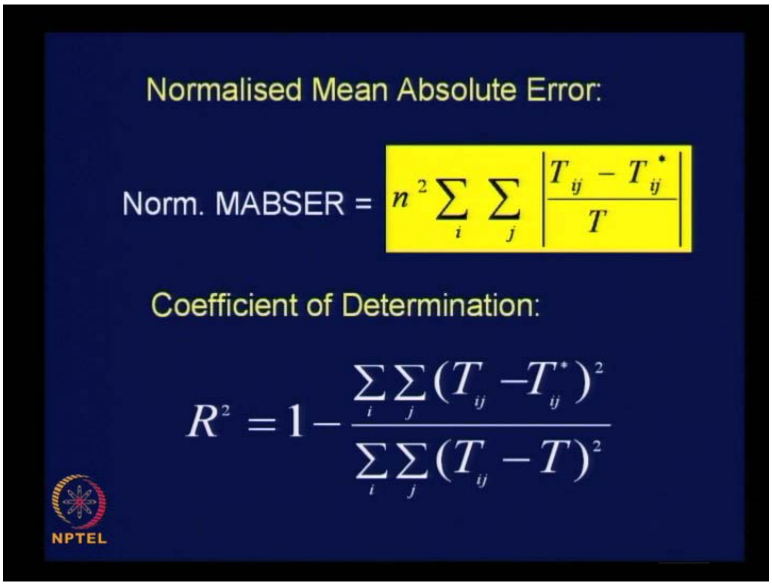

Then, there is another statistic used for the same purpose comparison of two sets of data, which is named as normalised mean absolute error, normalized mabser, that is how it is abbreviated is equal to n square into sigma over i sigma over j of absolute value of T i j minus T star i j whole divided by T. Of course, notation explanations are same as we have seen earlier, there is no difference at all, and coefficient of determination nothing but, R squared about which your familiar, but the formula used is slightly different, but gives you the same result; R square is given as 1 minus sigma over i sum over j of T i j minus T star i j whole square divided by sigma again over i then sigma over j T i j minus T whole square, T is the mean value mean observed value.

We have three statistical measures available for comparison, we can use any one of them or use all the three and then take overview of the comparison and choose the alpha value which gives you the least error, is that clear. So, with this basis let us take a small numerical example, and try to understand the procedure of calibration of doubly constrained gravity model.

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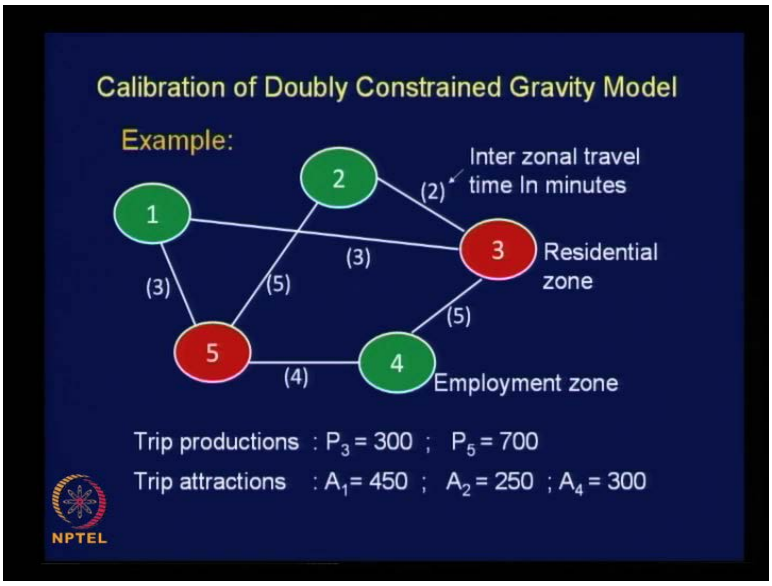

Calibration of doubly constrained gravity model, I am going the give the example, in the form of a figure, so that straight away we understand they given situation clearly, you can see totally there are 5 traffic zones shown here, in the picture; zones 1, 2, 3, 4 and 5, zones 3 and 5 shown in red colour are residential zones, implying that there will be only trip productions from these 2 zones. Zones 1, 2 and 4 which are shown in green colour are employment zones, there is going to be only trip attractions related to zones 1, 2 and 4. The numbers shown in parenthesis between the zones are the actual travel time in minutes for movement from 1 zone to other. Also please note that zone 3 for the purpose of trip connectivity or connected directly with zone 2, zone 1 and zone 4 right.

There is no connection of 3 with the other zone namely 5 similarly, zone 5 is connected to 1, 2 and 4 right this is how the zones are connected. And the trip production and attraction values are as shown here, P 3 is 300 trips, P 5 700 trips, A 1 450 trips, A 2 250 trips and A 4 300 trips; you can assume in this case also that, these trips are specific to a particular mode, with that understanding only we are proceeding further and for a particular purpose right.

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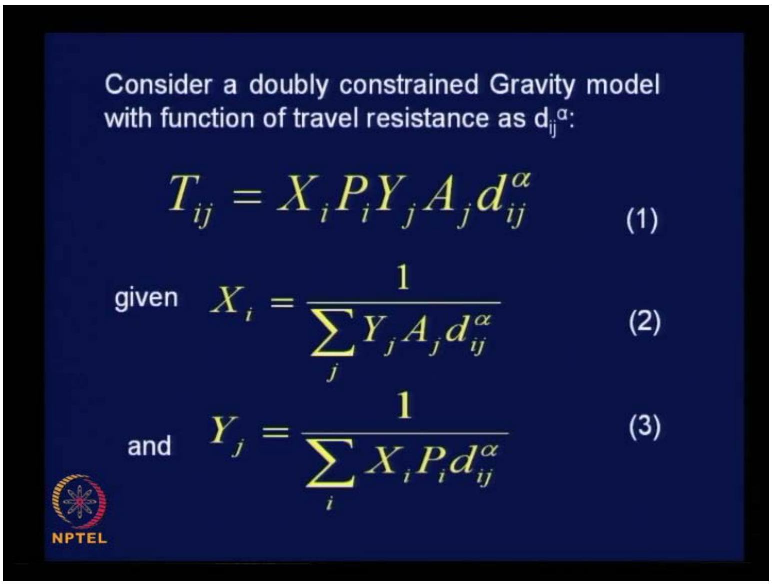

Now, let us consider a doubly constrained gravity model with function of travel resistance as d i j raise to power alpha, this is our consideration. We can consider different functional forms, in this case we just assume the frictional resistance to be following a simple polynomial form right, d i j raise to power alpha.

Then we can write, the doubly constrained gravity model as T i j to be equal to X i P i Y j A j d i j raise to power alpha, and we know X i is given as we have seen earlier to be equal to 1 by sigma j is equal 1 to n Y j A j d i j raise to power alpha and Y j is nothing but, 1 by sigma over i X i P i d i j raise to power alpha right.

As we discussed earlier, we are going to work with equations 2 and 3 first, with an assumed value of alpha and some assumption for Y j and try to balance equations 2 and 3 and then substitute the values of X i and Y j in equation 1 with one assumed value of alpha; that will be one trial. Then we will the change the value of alpha and go through the same process and then get back to the original equation, and get another set of model simulated values right.

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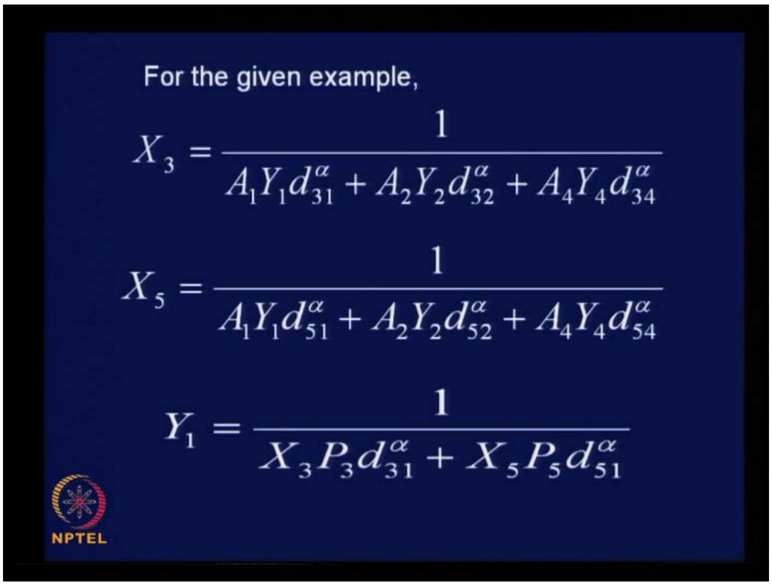

For the given example, this is how we can write the X i equation or equation pertaining to X i, X 3 can be written as 1 by A 1, Y 1, d 3 1 is it not, d i j is 3 1 here raise to power alpha plus A 2 Y 2 d 3 2 raise to power alpha and A 4 Y 4 d 3 4 raise to power alpha, 3 as I said earlier is connected to, what are the other zones connected to 3; 1, 2 and 4 that is how we are dealing with d 3 1, d 3 2 and d 3 4 clear. And X 5 can be written as 1 by A 1 Y 1 d 5 1 raise to power alpha plus A 2 Y 2 d 5 2 raise to power alpha plus A 4 Y 4 d 5 4 raise to power alpha, because zone 5 which is a production zone is connected to zones 1 2 and 4, is it not.

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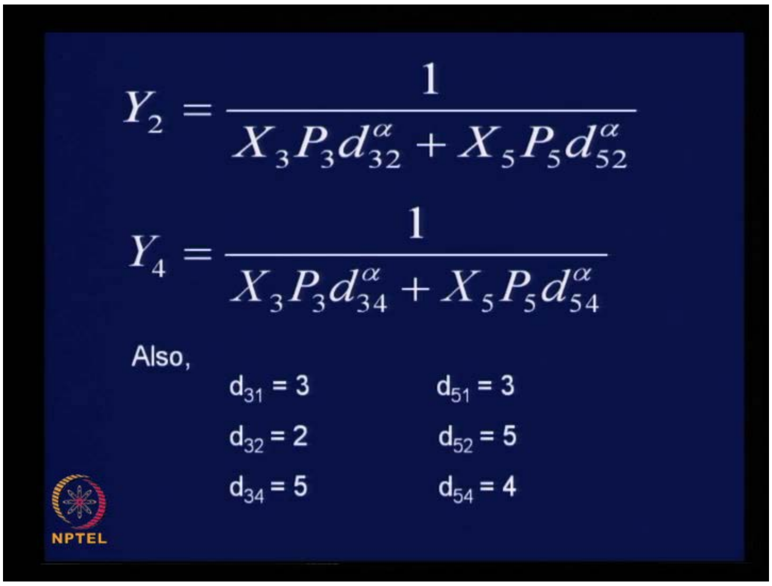

Y 1 can be written as 1 by X 3 P 3 d 3 1 raise to power alpha plus X 5 P 5 d 5 1 raise to power alpha, and Y 2 on the same lines you can write as X 3 P 3 d 3 to raise to power alpha plus X 5 P 5 d 5 2 raise to power alpha and Y 4 is 1 by X 3 P 3 d 3 4 raise to power alpha plus X 5 P 5 d 5 4 raise to power alpha. And of course, the values of d 3 1, 3 2, 3 4, 5 1, 5 2, 5 4 are given, just it is given in the figure again I am repeating the same numbers 3, 2, 5, 3, 5 and 4 right.

So, we are going to assume some value or alpha as well as Y j and work with equations 2 and 3, and to make the understanding easier I am giving this information.

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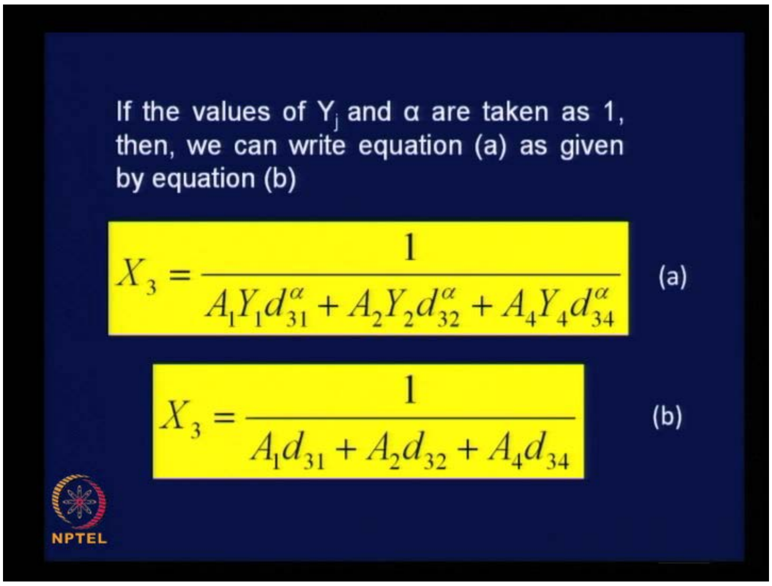

If the values of Y j and alpha are taken as unity, then we can write equation a as given by equation b, you may wonder as to how to choose the value of alpha to be unity suddenly, why not some other value are we sure that assumption of unity value for alpha will give us a rational result based on practical experience, planners have fixed some range for the value of alpha. When you express friction factor as a polynomial function of travel time or travel distance to alpha value normally falls within a range; that range will be normally known to the planners that is how we take some trial values of alpha initially may be lower bound and upper bound clear.

So, that is how you you need to accept or understand the fact that, we are taking a value of alpha to be just 1 and value of Y j been taken as unity just for convenience, we are taking it and then during iterative process automatically it will get changed.

We can write equation a as given by equation b, equation a is nothing but, the same equation that we have seen earlier pertaining to X 3 is nothing different, simply 1 by A 1 Y 1 d 3 1 raise to power alpha plus A 2 Y 2 d 3 2 raise to power alpha plus A 4 d 4 d 3 4 raise to power alpha. Now, simply substitute the values of alpha and Y as unity you get this equation, you can write X 3 to be like this very simple equation, that is what we are going to do, we are going to substitute the corresponding these values are known to us now is it not? We can find out X 3, because we know the value of A 1 as well as d 3 1 right, A 2 d 3 2 is known A 4 d 3 4 is known to us. So, we can substitute the values and get a trial value for X i, then this value will go into the equation for Y j, then we will come back to the equation for X i and repeatedly do the exercise until there is not much of change in the result.

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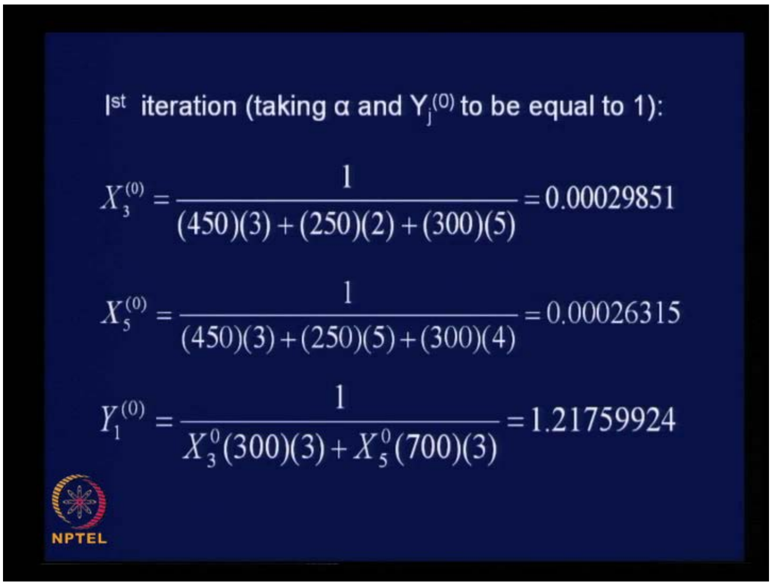

First iteration, taking alpha and Y j raise to 0 within parenthesis just to indicate that it is the first attempt, 0 has got no other meaning right to be equal to 1, we have taken both alpha and Y j to be 1 and start with the first iteration. As I indicated to you X 3 is simply 1 by the corresponding attraction value and distance plus corresponding attraction value plus into distance plus the attraction value and the corresponding distance, able to appreciate this particular equation equation for X 3 right. And similarly, X 5 substitute the corresponding values and get the result, please note that you are gone up to 8 decimal places, that is a level of accuracy expected otherwise, we will not be able to get consistent values for Y j and X i, if possible we can even go up to 10 decimal places or

12 decimal places, if you want to be more accurate. I stopped with only 8 decimal places here right, Y 1 0 on the same lines we substitute the known values and we get a value of 1.21759924, again holding the same number of decimal places.

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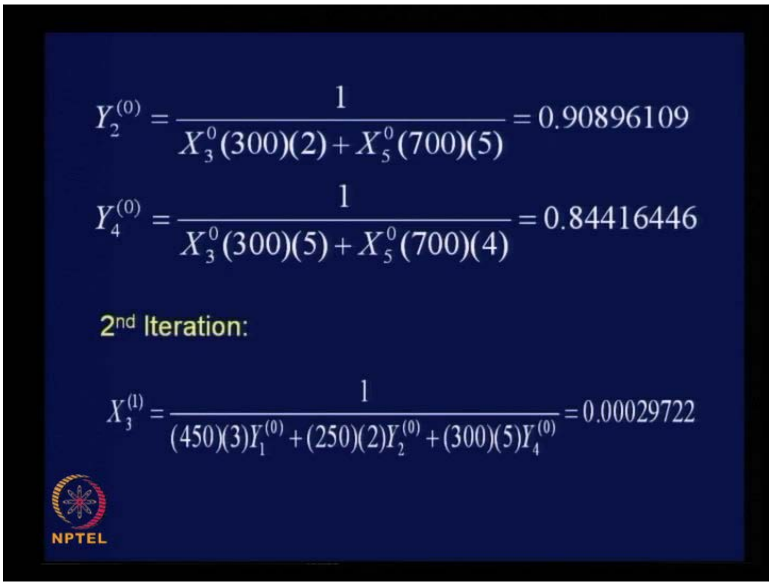

Y 2, 0.90896109, Y 4 substituting the corresponding values we are getting 0.84416446 right or with this we are completing one iteration, and we have to move on to second iteration. And we are not going to change the value of alpha at this stage, it is going to remain same until we get a consistent value for all the X and Y's X i's and Y j's right. You can see the difference here, what I do here is, X 3 i calculate as 1 by the corresponding attraction value, the next number is nothing but, the corresponding travel time for that link, and then I put the Y 1 value which we have got in the previous iteration, earlier this was not appearing in the first iteration, because we have taken that as 1 unity right.

Now, we have got some value for Y 1 right, that is how I have write written that, I have not really not substituted the value it is understood, once you substitute that value your getting this result, for want of space I just have not substituted the actual calculated value in the previous iteration right. So, we just substitute the actual value of Y 1 0 here, plus 250 into 2 Y 2 0 plus 300 into 5 Y 4 0 if you do, so you are getting a value of X 3 to be 0.00029722 that is the value of X 3.

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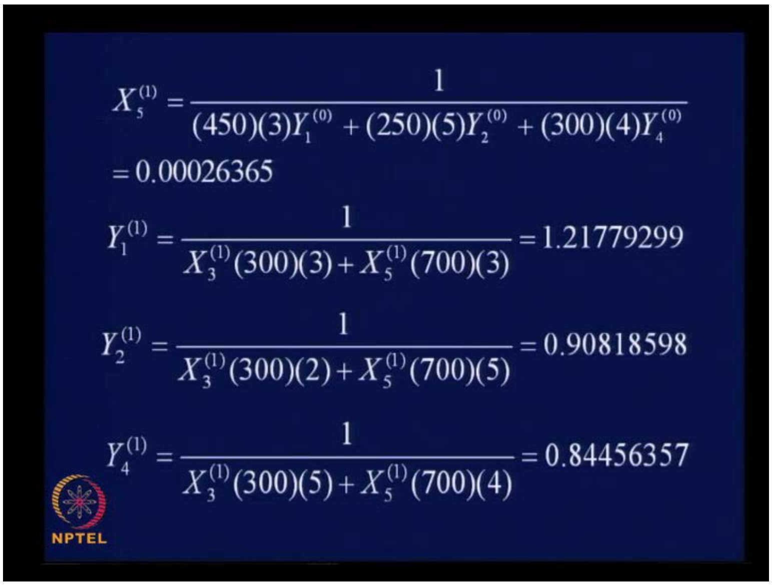

On the same lines proceed with the other calculations, X 5 again substituting Y 1 0, Y 2 0 and Y 4 0 you get X 5 value to be 0.00026365, then Y 1 1 will be 1 by X 3 1, please note it is not X 3 0, X 3 1 because, we have just got X 3 1 value, so you can use that immediately right, X 3 1 can come into this calculation, because we already have the value calculated using Y 1 0, Y 2 0 and so on. So, we can use the current value here, X 3 1 then the corresponding production and then the distance plus X 5 1 into 700 into 3 and you get a value of Y 1 to be 1.21779299 and Y 2 1 on the same lines, we get the value to be 0.90818598 and then Y 4 1, 0.84456357.

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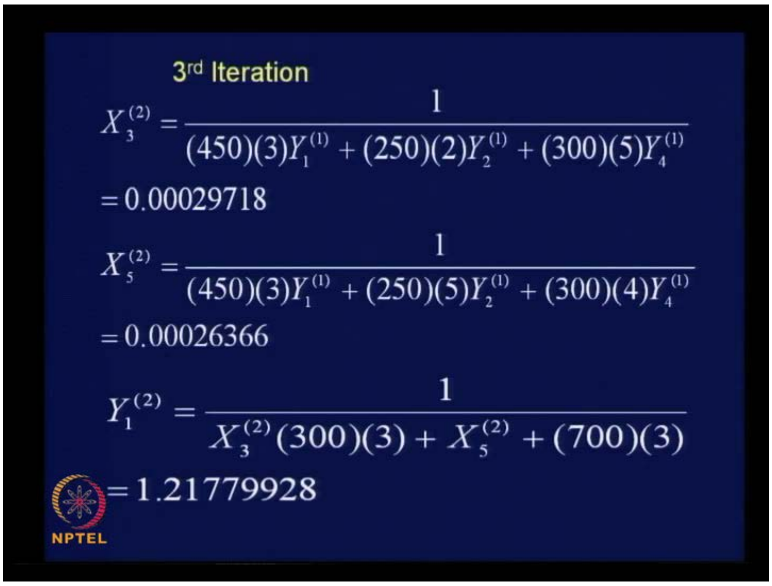

Now, third iteration repeats the same we have now, the value of Y 1 available to us to calculate X 3, so latest value of Y we are putting in the subsequent calculations and X 5 we calculate as shown here, and Y 1 please note we are using X 3 2, because just we completed the calculation of X i.

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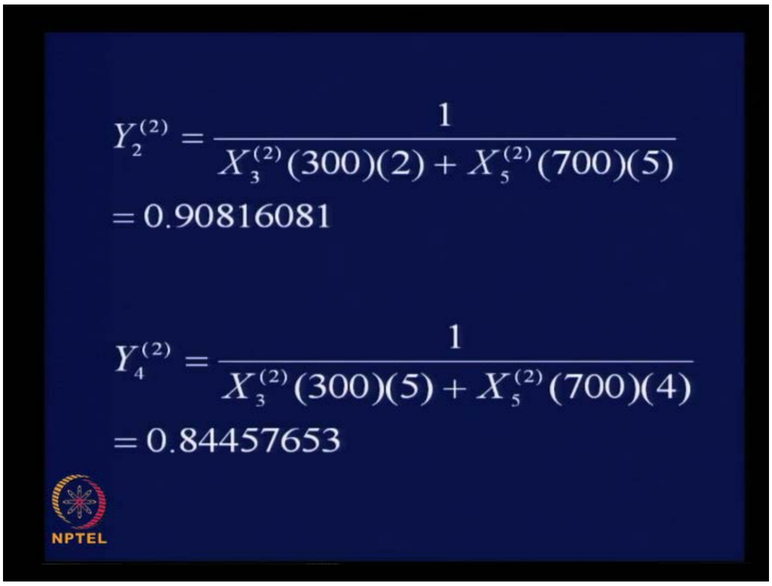

So, put that value and get the value of Y 1 and Y 2 and then Y 4.

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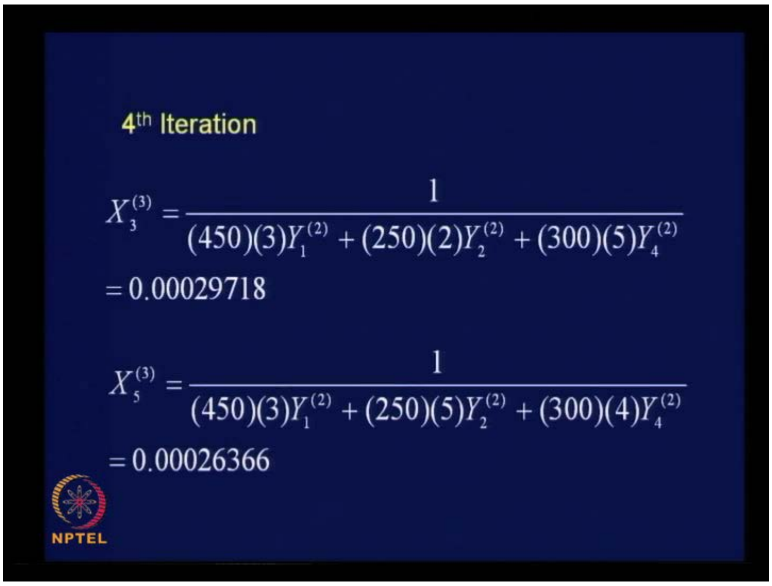

And 4th iteration you may wonder, why we are going on doing iteratively, this implies that there is no consistent value of X i's and Y j's at times so far, may be little later I will show you the comparison right, X 5 we calculate as given here.

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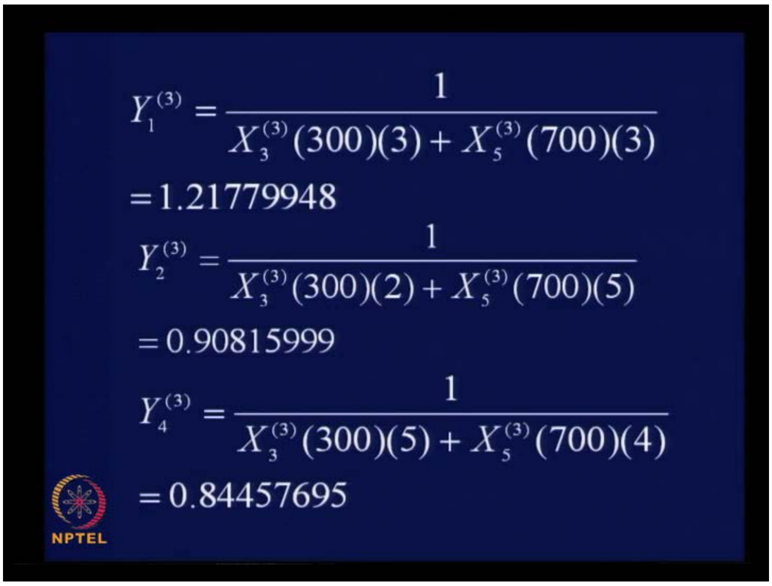

And then, we calculate the value of Y 1 3, Y 2 3, Y 4 3 and go ahead with 5th and 6th iterative, steps also on completion of 5th iteration and 6th iteration you may get a set of values for the X i's and Y j's, I will just show you the result of 5th and 6th iterations.

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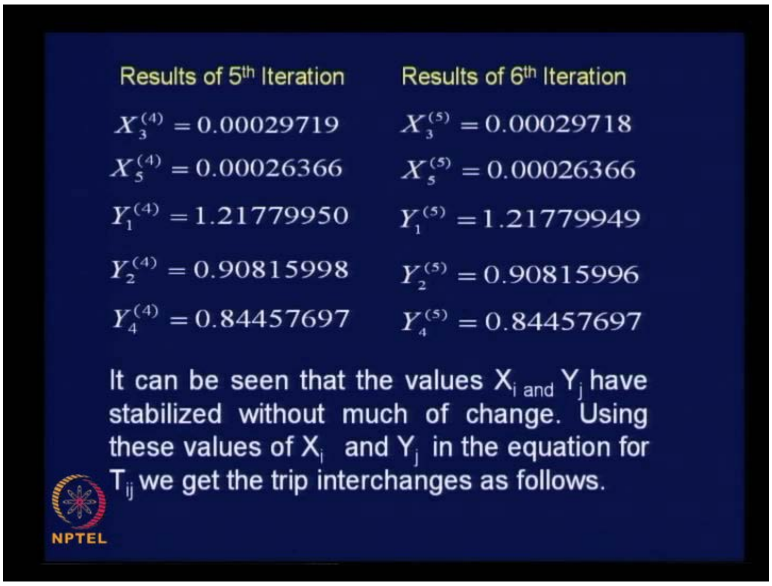

This is the value of X 3 4, your getting on completion of 5th iteration right and X 5 value is this, Y 1 this much, Y 2 and Y 4, then let us do the 6th iteration also and get the corresponding values. Now, we are getting X 3 5 value to be this much, now look at the 2 numbers, that we obtained through iteration 5 and 6, what is a variation, still they are not the same there is variation in the 8th decimal place, it is up to us to say yes or no, I think all of you are inclined to say almost yes.

Let us see, the result of other calculations X 5 4, where is a perfect match no variation at all up to 8th decimal place, Y 1 there is variation in the last decimal place right, Y 2 there is variation in the last decimal place, and Y 4 there is a perfect match. Shall we say that, we have converged on the correct value of X i and Y j as I said the right way is proceed further, and see whether the convergence is still possible or we are ending towards divergence; normally in practice when there is a match up to 6th decimal place in practice, the plan is accept the consistency of X i and Y j and substitute the values of these factors in the parent doubly constrained gravity modelling.

So, we will say that this consistency is acceptable, and we can use these values in the gravity model, it can be seen that the values of X i and Y j have stabilized without much of change that is important. Using these values of X i and Y j in the equation for T i j we get trip interchanges as follows. Now, only we go back to equation 1 for T i j substitute the values of X i and Y j, because we have the values here right, and then we have assumed alpha value to be unity that remains and substitute those values and get the result of T i j, T 3 1, 3 2, 3 4 whatever like changes are there we can get, and I am giving you directly the calculation details as well as the result.

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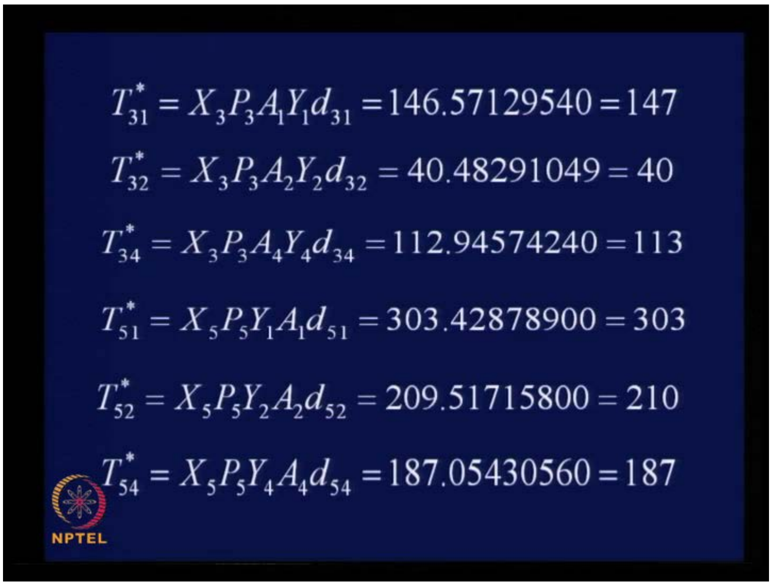

So, T 3 1 is going to be X 3 P 3 A 1 Y 1 d 3 1 and the values are known, so what we do is I am just giving you the result only, not the details of calculation only thing is to emphasize the point that, we cannot have fractions in the final result I have rounded off the value to the nearest whole number, we are getting 146.57129540 and so on and we just round it off to 147. T 3 2, in fact it is T star 3 2, because it is model simulated value to differentiate between T i j and T star i j and we get 40.48 and we just simply round it off to 40 right; you may ask me why not 41, and you must take the overview, look at the other numbers and check whether our rounding off procedure in this case is right or wrong. T star 3 4, 112.9457 can be obviously, rounded off to 113, T star 5 1, 303.4287 rounded off too simply 303, T star 5 2, 209.51 rounded off to 210, T star 5 4, 187.05 rounded off to 187 right.

Now, you must also see that these numbers are not violating the total of the values initially given to us, total production and total of attraction keeping that in mind you must be careful in rounding of exercise; that is why particularly, even though you can round off 0.48 to be 0.5 and then round it to to 41, I am just leaving it is leaving it as 40, mainly to take care of the constraints related to P i and A j.

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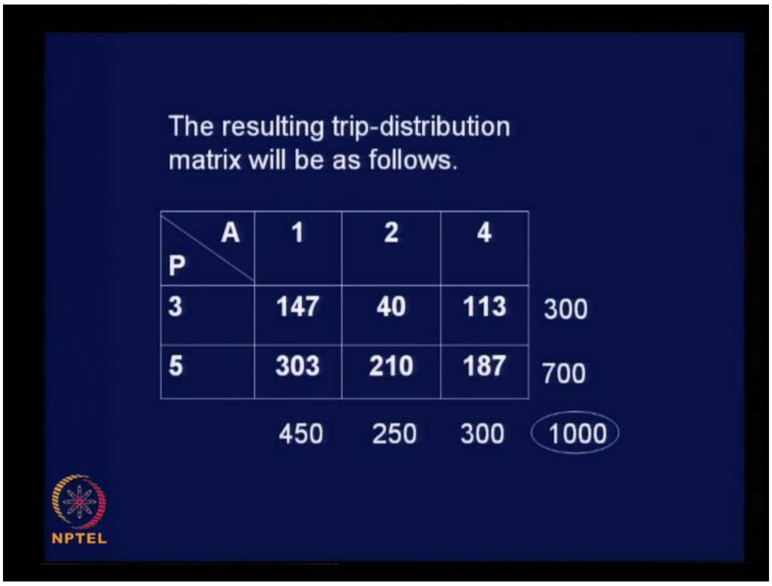

So, this is the resulting matrix, please note that these numbers were given to us right, P 3 were 300, P 5 was 700, A 1 was given to us as 450, A 2 250 and A 4 was given to us as 300, had I changed this 40 to 41 we will have problem here right. So, that is how, I said when dealing with large number of cells you should be careful in rounding off, and see that we are not violating the constraints related to P i and A j, still in most cases you will be able to logically round off the fractions to nearest whole number.

So, this is how we get the theoretical matrix, and this has to be compared with the actual matrix and then based on the statistics, we need to check. whether the assumed value of alpha is right or not. So, this is one exercise as I said similarly, we need to assume different values of alpha may be 1.5 for second trial, 2 for third trial 2.2 whatever for fourth pair and so on, and then choose the alpha value which gives the least error, to understand this process let us take a case study.

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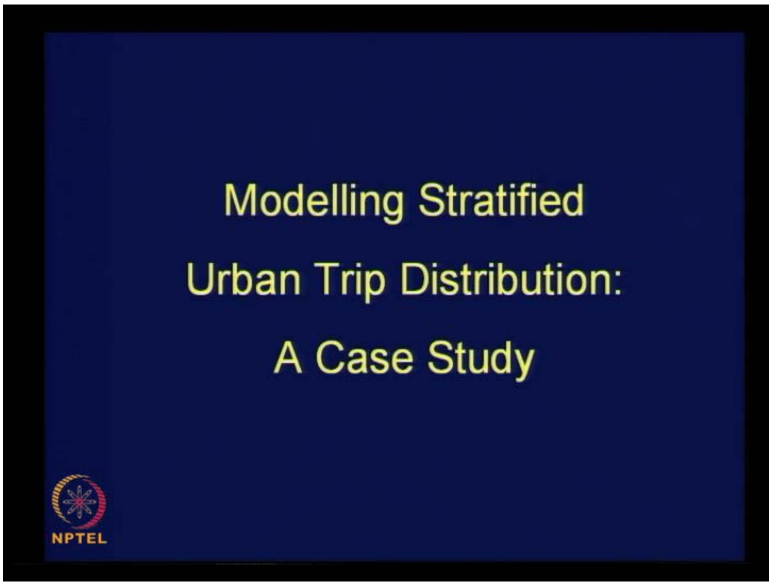

So, that we have a feel of applying this model for a real life situation, and a case study tends to the city which is already known to you. So, that your more comfortable and understand the situation in the field.

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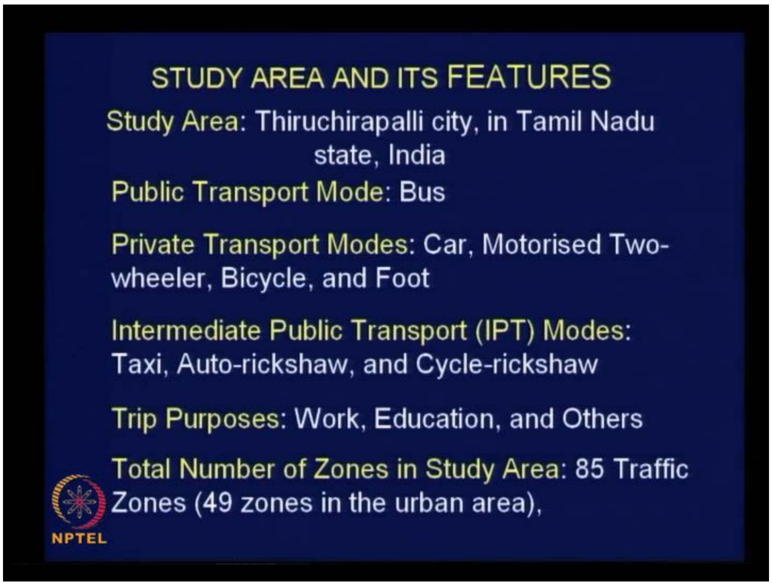

And the study city considered is Tiruchirappalli city in Tamil Nadu state India, some basic information about the city as I mentioned to you earlier, there was only one mode of public transport which is bus. And private transport modes available where car motorised, two-wheeler, bicycle and put foot right foot of course, is truly a private transport mode, is it not. An intermediate public transport IPT are taxi, auto-rickshaw and cycle-rickshaw, trip purposes as we have seen earlier work education and others, we have classified the trips into three categories because, the percentage of trips made for other purposes was how much, anybody who can recollect the number? 6 percent, it is only 6 percent, 49 for work, 45 for education and just 6 percent for all other purposes as far as this particular city is concerned.

And total number of zones, traffic zones in the study area were 85, 85 traffic zones you may recall that I mention to you that, the population of city at that time was around 1 million, it was not exactly city the population of the study area which includes the surrounding panchayats, town panchayats etcetera where from there is a regular commuting by people in to the city centre, it was just 1 million. And number of traffic zones were just 85, to look at this number in comparison with the division of urban area into traffic zones for study internationally this is a very small number, ideally the number of traffic zones should have been minimum 200, 200 traffic zones that is it in an international standard.

And why then only 85 traffic zones for this case, what might have been the constraint or what is the problem with less number of zones, what is the real technical problem, when you divide the area in to a small number of traffic zones, it is very simple please remember, we consider zone centroids as the points of origins and destinations of trips, we have the large area for zones you will have only one point as a exact point of trip origin and trip destination, is it not? But, in practice it may not be exactly matching with the reality right, you may combine Velachery IIT campus, Adayar area and Saidapet all together and fix one point may be near Anna University as the point of trip origin and destination which is unrealistic, is it not? The land dues also may not be that homogenous, so that is how larger zones will produce unrealistic results.

So, you should have zones of compact and homogeneous land dues of manageable size normally around 1 to 1.5 kilo kilometre radius in general zone size except in cases where you have vast area of just barrel land in the fringe areas of your study a mot for your study in case of some cities otherwise, zones size should be as small as possible, so that you get accurate results replicative of the real travel path clear. So, please understand 85 is not internationally accepted number, but still we have done it, because of the constraints related to cost.

When you divide area into more number of traffic zones, you are going to collect more segregated data, employing more peoples, spending more money, spending more time right that is the reason why, the number of traffic zones have been reduced to only 85. But still we can appreciate this effort, because at that point of time this kind of comprehensive transport systems study was done only for few cities in our country, even today I would say that systematic comprehensive transport planning study has been done only for few cities in our country, the mega cities and few other cities like Hyderabad, Bangalore and so on, other cities are just managing without proper database for transport system analysis and planning clear.

That background if you look at this effort its really good, Tiruchirappalli is very small city compared to the other urban areas, so that way these really a good sincere effort and it was divided into 85 traffic zones and there were 49 traffic zones in the urban area and rest of the zones were the area surrounding the municipal boundary.

So, with this basic information about the study area, we will stop for today and to check what we have done in this class you may recall, we have just very briefly discussed about the difference between singly constrained and doubly constrained gravity model. The constraints are mainly related to trip production and trip attraction, in the case of singly constrained gravity model which we have used earlier. The constraint related to trip production was put into the model, before the model was applied for distributing trips right, whereas in the doubly constrained gravity model, we put both the constraint at the initial stage itself and then finally, use the gravity model for distribution of trips.

So, that in one go you get the distribution result in the form of matrix and checking for the correctness of the trip distribution is based on comparison of their model simulated and field observed trip distribution matrices clear. With this, we will close for today and we will continue our discussion in the next class.