Urban Transportation Planning
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Module No. # 05
Lecture No. # 22
Trip Distribution Analysis contd.

This is lecture 22 on Urban Transportation Planning; we will continue our discussion on Trip Distribution Analysis in this lecture. Before we continue our discussion, let us recollect briefly what we did in the previous class, you may recall we discussed about the general formulation of the gravity model of trip distribution, and then apply the gravity model for a given situation involving three traffic zones and the friction factor values for a movement between the traffic zones were also given to us.

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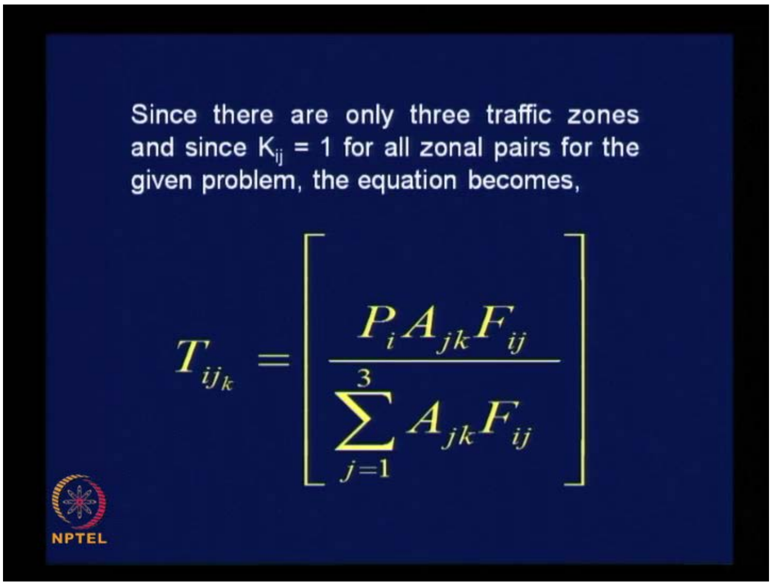

With that information, we just understood that for this particular case sends only three traffic zones for involve and K i j zone to zone adjustment factor is given as 1, we wrote the gravity model in this form T i j k was written as P i A j k F i j divided by sigma j equal to 1 to 3 only three traffic zones, A j k F i j right. Using this formulation, we found T i j values for K is equal to 1 first iteration, you have just completed one iteration.

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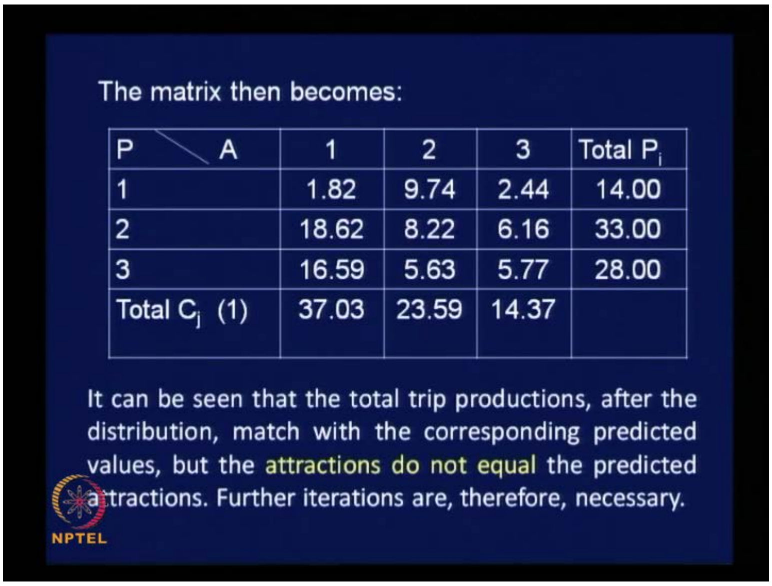

And the result of the first iteration is this, this is the result we got in the previous class. The cell values of the matrices, matrix is nothing, but the trip distribution between zonal pairs right and we found that the sum of the cell values along each road works out to the corresponding total trip productions of the zones, whereas when you sum up the cell values along columns, they are not giving values corresponding to the total trip attraction by the traffic zones, that is a problem.

In addition, please note that when you add the cell values along the row, you are not exactly getting the whole number that we have written in the last row. We are not adding up to exactly 14 exactly 33 and exactly 28.00. If you add up, it may enter with some fractional number which is very close to the whole number indicated in the column right. When you are rounding off the values to the higher whole number or if you are leaving of the decimal part when it is less than 0.5, you will be getting these numbers as 14, 33 and 28 right. And if you look at the trip attraction values, we are getting 37.03 against the given value of 33 in the original problem and we get a value of 23.59 against the given value of 28 in the problem and we are getting a value of 14.37 instead of 14, trip attraction values given to us for zones 2, 3 as well as 1 or 33, 28 and 14 similar to the numbers, but the zone numbers are different when you compare productions and attractions.

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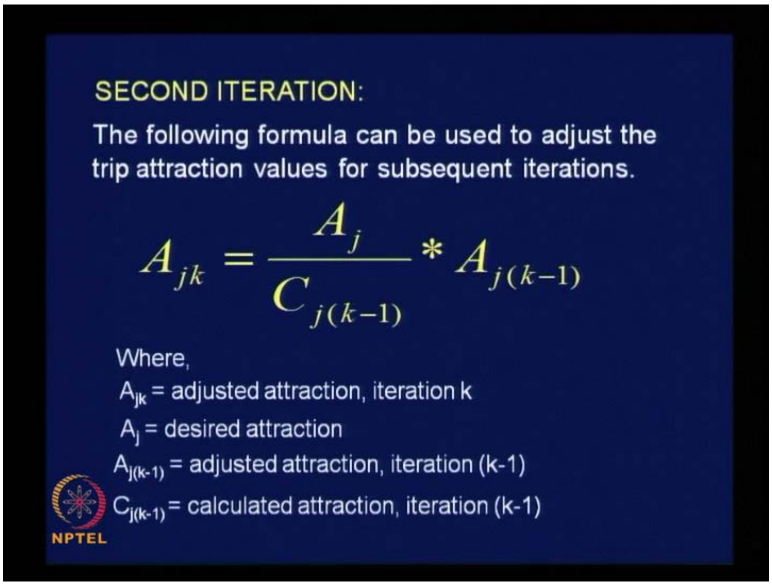

Now, our aim should be to see that the sum of the cell values along each column also it is how to the actual given trip attraction values. For that purpose we, this is what we discussed now there is no need to repeat again. And we discussed about some correction procedure to calculate an attraction value which can be used for the subsequent iteration and A j k is a adjusted attraction for iteration k, A j is the desired attraction which is known to us for the Bezier condition right and A j k minus 1 as you can guess is a adjusted reaction pertain into iteration k minus 1 the previous iteration, right. And of course, C j k minus 1 is calculated attraction for iteration k minus 1, so that is how we just formulate this adjustment procedure, you can see here, if you use this adjustment procedure, you will find that if your calculated attraction values very high, this procedure will result in a reducing effect and if your calculated value is very low, then this procedure will help increase the value, C j k minus 1 is in the denominator, which is the calculated value of attraction. We will see with the numerical example how this correction procedure works.

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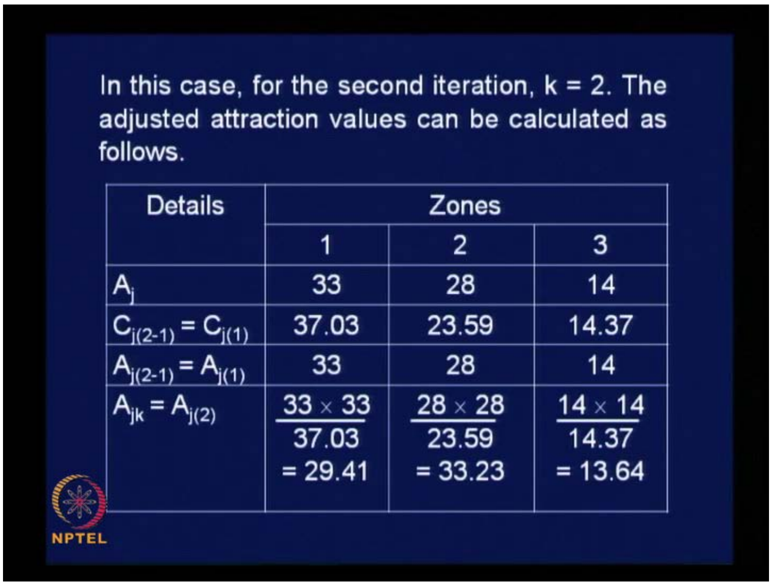

For the second iteration, k is equal to 2, the adjusted attraction values can be calculated using the previous formulation like this. I have again listed the values of A j as 33, 28 and 14, these are the actual desired attraction values. C j 2 minus 1 or in this case, C j 1 which we get after the completion of first iteration is 37.03, 23.59 and 14.37 right and the value of attraction which was given as input for the iteration, that was just completed is A j 2 minus 1, is it not? That is A j 1.

In this case, A j 1 happens to be A j itself, because it is first iteration, is it not? That is how A j 1 is also given as 33, 28 and 14, then use the correction formula get the value of attraction A j 2 for second iteration and that is obtained as 29.41 right 33.23 and 13.64. Check what has happened to the previous value, we have got a calculated value of 37.03 as trip attraction for zone 1, which is much higher than the desired value of 33, this has to be reduced. By using this correction procedure, we get a value of 29.41 as attraction value for zone 1 which will be given as input to the subsequent iteration and we are going to check whether we are able to get the desired result or not. And similarly, we have got a value of 23.59 as A j 2 instead of 28; a lesser value, the correction procedure has given as high value, so when you put in this higher probably there is scope for improve increasing the value of A j 2, that is how the correction procedure works, here instead of 14 we have got 14.37.

So, we are going to input the value of only 13.64, because still we want to reduce this to 14 and with these attraction values, we will be repeating the calculations to get the value of T i j for each of zonal pairs clear.

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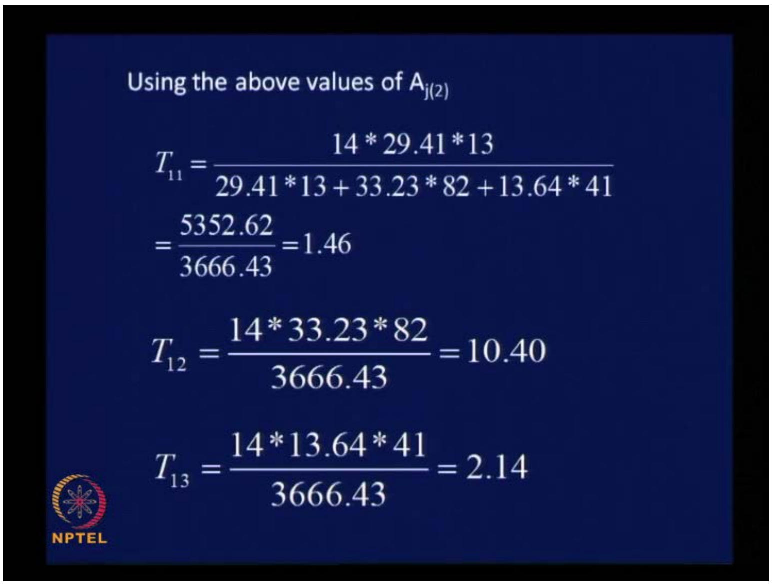

Now, let us work out T 1 1 and works out to 1.46, only difference is the A j values are different in this case is it not? T 1 2 10.40, T 1 3 using the same procedure 2.14.

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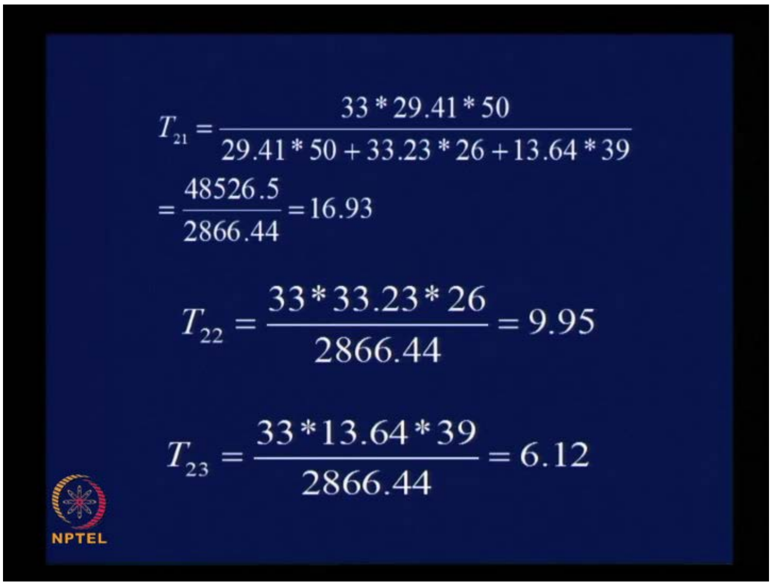

Then, trips from zone 2, T 2 1 works out to 16.93, T 2 2 works out to 9.95 and T 2 3 is 6.12.

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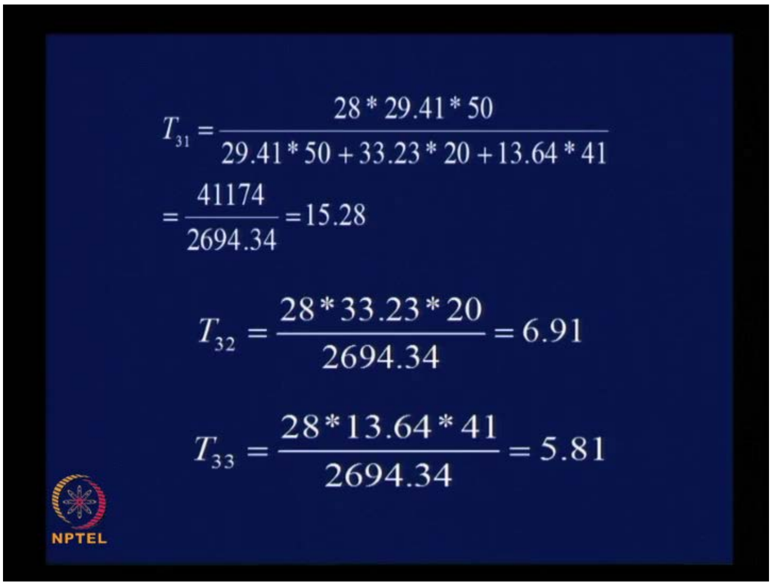

And for zone 3, T 3 1 15.28, T 3 2 6.91, T 3 3 5.81, now we are ready with the values to be filled in the matrix to check whether we are able to get the desired attraction values.

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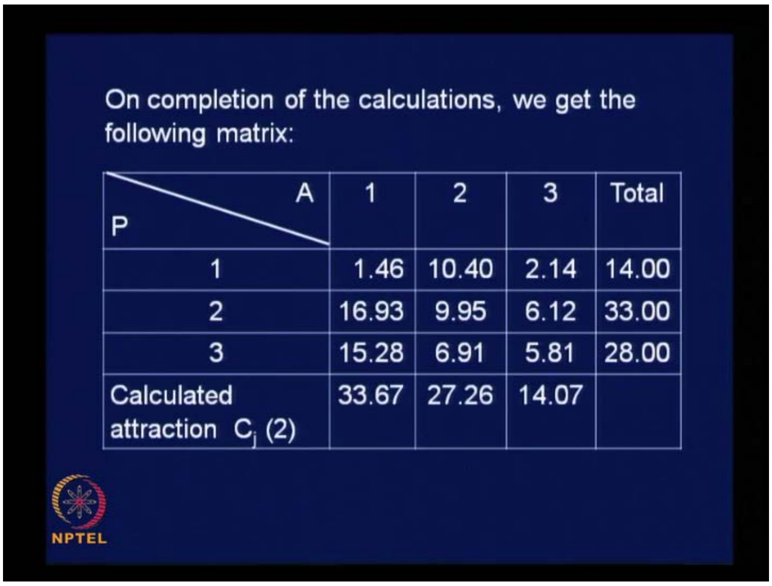

Let us present the result in the form of a matrix I shown here. As usual, when you add up the cell values along roads we are getting the actual observed production values of 14, 33 and 28, you can check for every iteration, you will be getting it right. And if you look at the attraction values, now the values are little better than what it was in the first iteration we get 33.67 instead of 33, 27.26 instead of 28 and 14.07 instead of 14 right.

Now, the question is, where to stop or when to stop iterative procedure? Are you happy with these values? Now if you logically rounded off even the attraction values 33.67 can be rounded off to only 34. Ultimately, we have to round off all these numbers including each cell value to a whole number then only your trip distribution matrix is valid, logical. You cannot have fractions in your final result right, when you try to round off 27.26, we end up with 27, we are not matching with the desired values.

So that is why we must have a feel of the need for continuing the your iterative process, so there is no need for iterative process if by rounding a procedure, you are able to get the desired numbers, whereas here it is not so, we need to continue our iteration.

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THIRD ITERATION:

The adjusted attraction values Aj(3) are calculated as below:

Details	zones		
	1	2	3
A_j	33	28	14
$C_{j(3-1)} = C_{j(2)}$	33.67	27.26	14.07
$A_{j(3-1)} = A_{j(2)}$	29.41	33.23	13.64
$A_{jk} = A_{j(3)}$	$\frac{33 \times 29.41}{33.67} = 28.82$	$\frac{28 \times 33.23}{27.26} = 34.13$	$\frac{14 \times 13.64}{14.07} = 13.57$

Third iteration, the adjusted attraction values or to be calculated first and the calculation is similar to what we have done earlier. Now, we can see interestingly the value of A 1 that we got at the end of second iteration was 29.41 right, the value given as input for second iteration was 33.67 and the desired value is 33. So, when you do this adjustment, we end up with 28.82, we are going to give an input which is much less than the desired value right and we will check whether we are able to come closer to the desired value of 33 right. And in the next case, you can see A j 2 after second iteration had been 33.23 and the input was 27.26 and now, we are going to give an input of 34.13 right. And for A j 3 it is going to be 13.57 against the input value of 14 point going to be 13.57 against the input value of 14.07 with these A j values, let us proceed with third iteration.

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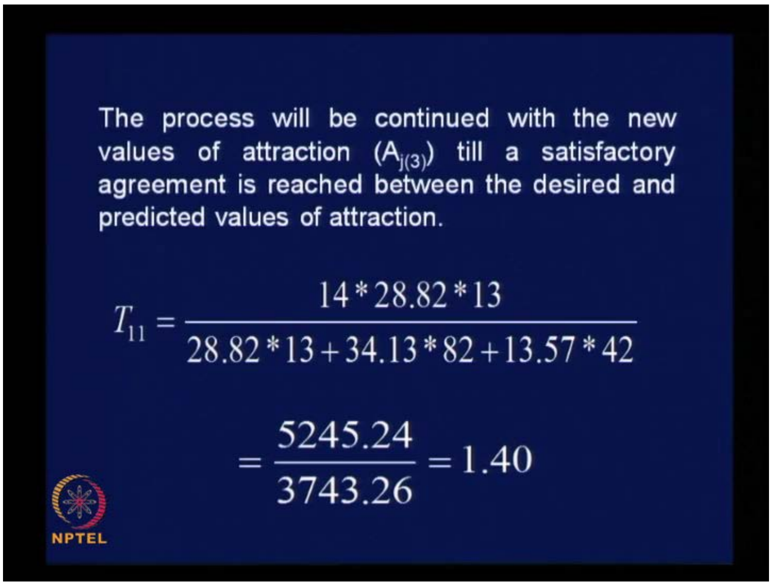

The process will be continued with the new values of attraction. In this case, A j 3 till a satisfactory agreement is raised between the desired and predicted values of attraction, that is our target.

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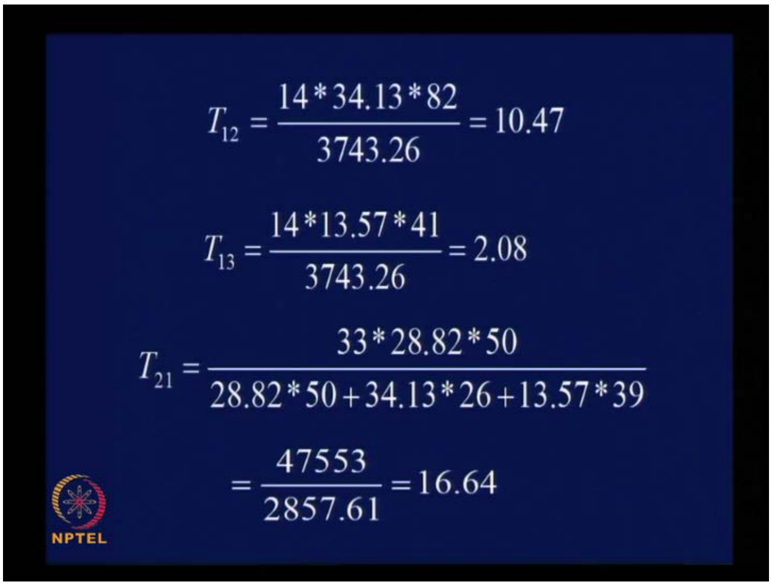

So, let us go ahead with the calculation of T 1 1 as 1.4, T 1 2 10.47, T 1 3 2.08, T 2 1 is 16.64.

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$$T_{22} = \frac{33*34.13*26}{2857.61} = 10.24$$

$$T_{23} = \frac{33*13.57*39}{2857.61} = 6.11$$

T 2 2 10.24, T 2 3 6.11, T 3 1 15.06, T 3 2 7.13, T 3 3 5.81.

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$$T_{31} = \frac{28*28.82*50}{28.82*50+34.13*20+13.57*41}$$

$$= \frac{40348}{2679.97} = 15.06$$

$$T_{32} = \frac{28*34.13*20}{2679.97} = 7.13$$

$$T_{33} = \frac{28*13.57*41}{2679.97} = 5.81$$

This completes the third iteration, let us put the result in the form of a matrix and check whether we have achieved the desired result.

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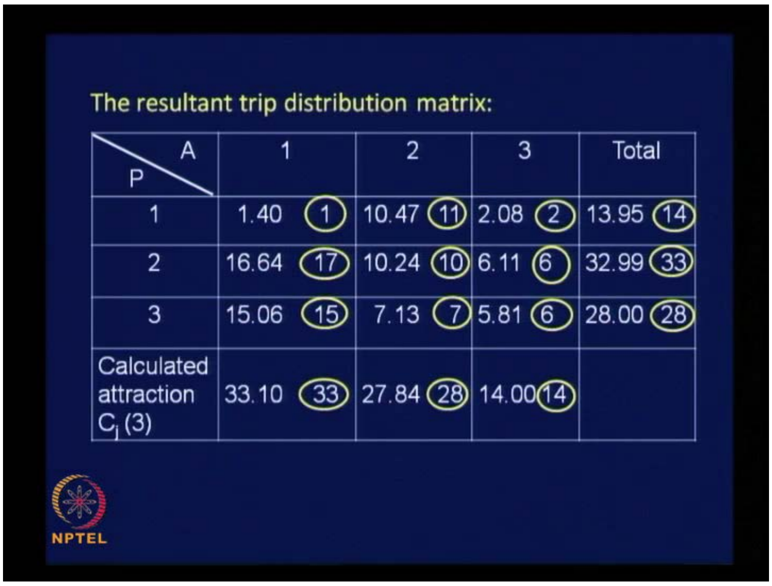

P \ A	1	2	3	Total
1	1.40 (1)	10.47 (11)	2.08 (2)	13.95 (14)
2	16.64 (17)	10.24 (10)	6.11 (6)	32.99 (33)
3	15.06 (15)	7.13 (7)	5.81 (6)	28.00 (28)
Calculated attraction C_j (3)	33.10 (33)	27.84 (28)	14.00 (14)	

This is a result; I am showing you simultaneously the desired values also. First, let us try to check the attraction numbers, we have got 33.1 which can be rounded off to 33, 27.84 can be rounded off to 28 and 14.00 exactly we are getting, so we accept the number right. Also, please check the logic of rounding off of all the cell values starting from 1 1, 1.4 rounded off to 1, 10.47 rounded off to 11, 47 becomes to 0.5 then it become 11 and 2.08 gets rounded off to 2 and please note in reality you may have number of cell values about 100 in a row. When you do this rounding off business, simply rounding up to a higher number if refraction is more than 0.5, rounding up to lower number when it is less than 0.5, the second decimal place or third places may have some effect. In such a case, in one or two cells you may have to make a compromise which should not affect your overall result right.

So, that is to be kept in mind; in a certain case, some 10.49 may have to be rounded off to only 10, to get adjusted with overall requirement, so that is a reality. And in second row to look at 16.64 rounded off to 17, 10.24 to 10, 6.11 to 6 right, 15.06 to 15, 7.13 to 7, 5.81 to 6 and the totals or totaling up to exact production values of 14, 33 and 28, and if you add up the cell values along each column to get exactly the desired values of attractions of 33, 28 and 14. Even though it is iteratively fine, there it is possible to achieve the desired result with repeated working with the gravity model with input of the adjustment procedure right, this is how we work with this gravity model.

Next we will see, how to really calibrate the gravity module, you may recall in this problem the F i j values were given to us right, we got F i j values in the form of a matrix and those values were substituted, but in realities F i j values will not be known to us, you may have Bezier trip distribution data using that, data we should be able to work out the F i j value for zonal pairs and that should be used in the gravity model for actual distributing the trips or getting the T i j values. So, we have to check or try to understand how to go about getting the value of F i j to be used in the gravity model formulation.

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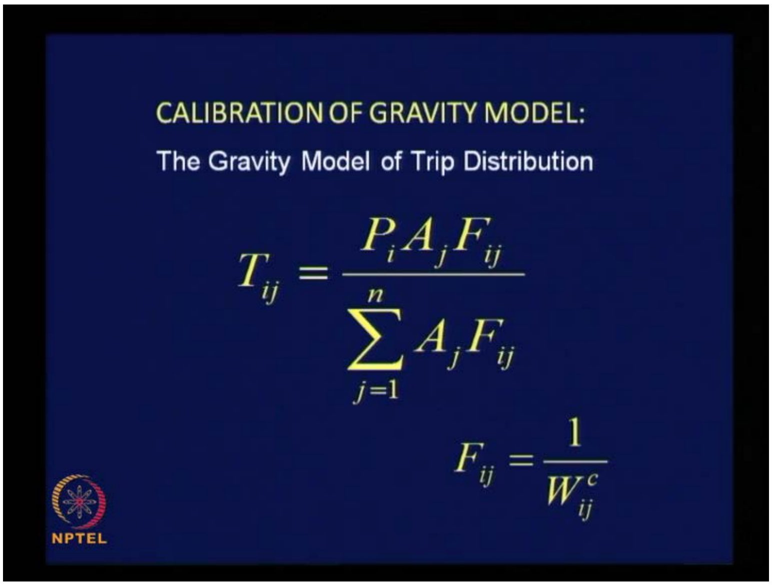

And this procedure is what we call as calibration of gravity model, just recollect the general form of the gravity model; this is the general formulation T i j is P i A j F i j divided by sigma j is equal to 1 to n A j F i j our interest here is to get the value of F i j. F i j is the friction factor which represents the travel impedance between zones is it not, that is how we understood F i j and you may recall originally it was 1 by W i j raise to power c and for our convenience.

We have just taken that factor as F i j right, it is inverse of a function of travel impedance between traffic zones this impedance can be explained using travel time, travel cost, travel comfort, travel safety all together as a bundle all transformed into equivalent money value, that is how we understand W i j clear.

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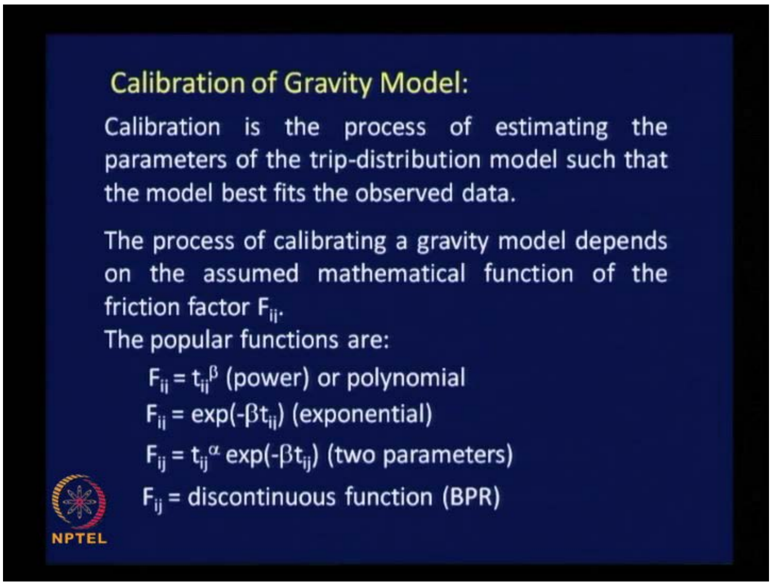

And calibration is a process of estimating the parameters of trip distribution model such that, the model best fits the observed data. Now the question is what exactly is the parameter that, we are going to estimate, the process of calibrating a gravity model depends on the assumed mathematical function of the friction factor F i j; initially we have taken F i j as one one W i j raise to the power c. W i j is the bundle of several factors related to the modes of transportation including foot bicycle I P T public transport motorized personal vehicles and so on but, normally we do trip distribution by segmenting data based on more use for travel.

We also discussed about this in the previous class, why should we discuss segment data based on mode use for travel, any response cannot put the data data data's pertaining to all the modes of travel together and do trip distribution. You may recall I gave the example of trips made by foot, distribution of trips made by foot will be confined to the set of few zone if you consider one zone may be the adjoining zones will be involved in trips made by foot we consider trips made by bicycle distance cells may be slightly more with motorized modes of transportation the spread of trips will be covering a wider land squares is it not. So, obviously there is a reason to segment the data based on mode used for travel for the purpose of trip distribution. Once you segment the data based on mode for travel, then travel time is going to be same, because only one one mode we are talking about isn't it average travel time by a mode is going to be same travel cost is going to be same remaining, will be remaining constant comfort safety all this factors will be almost constant terms right so if your distribution is mode based you can consider travel time as a soul basis to access the frictional resistance for movement between zones you may wonder why not travel distance? Why travel time? You have to answer these questions why not take travel distance? As a basis why should we take travel time?

Yes travel distance can replicate the effect of travelling time provided the transport infrastructure in the form of the way, the vehicle, the control and the terminals are same throughout network and which the particular mode is used. In practice it may not be so on a route a stretch of 2 kilometers may have very narrow road, another stretch may be having wider road right, this trip may involve a length of 5 kilometers; there may be another route with very wide route throughout the trip length may be about 6 and a half kilometers between the same origin and destination and if you compare the travel time the time by the longer route, relatively longer route may be less compare to the time through the shorter route and as urban travelers we are concerned about travel time, how fast I can reach a destination by a particular mode and the travel resistance felt is normally in terms of time there then distance is it not. So that is how it is always taken as time and not distance, because of this problems this implies that it is possible to give F i j as a function of travel time right.

The popular functional forms are these F i j is given as t i j raise to power sum parameter beta it could be beta a, b, c whatever right and this form is called polynomial form or power function of F i j. And F i j can also be expressed in negative exponential form e power minus beta times t i j, also we can express F i j using two parameters t i j raise to power alpha an then e power minus beta times t i j. You may wonder why so many functional forms it depends up on the actual travel pattern right, so each city may have its own transport system and the road network.

So, the effect of frictional resistance will be explained in different forms depending up on the field condition, that is why a given different alternative forms even though in most cases the polynomial form might suit but, there are other alternatives available so that depending up on the need you can try the other functional forms too.

There is one more form simple discontinuous function recommended by BPR Bureau of Public Roads U S A, this is nothing but, combination of these functional forms based on the trip length expressed in the form of travel time, you can choose the function for trips from 0 to 2 kilometers, then for trips from 2 to 4 kilometers you can have another functional form right they encourage discontinuous function. Whereas, in the other cases once you fix a functional form irrespect to the travel distance it is going to be same right they felt it may not work well for all trip lengths it is better to have discontinuous function with different functional forms depending up on the length travel involved, that was recommended by bureau of public roads.

And let us just have a feel or the graphical form of these functions, so that, you can have a feel of the variation of F i j over travel time or travel distance mostly travel time.

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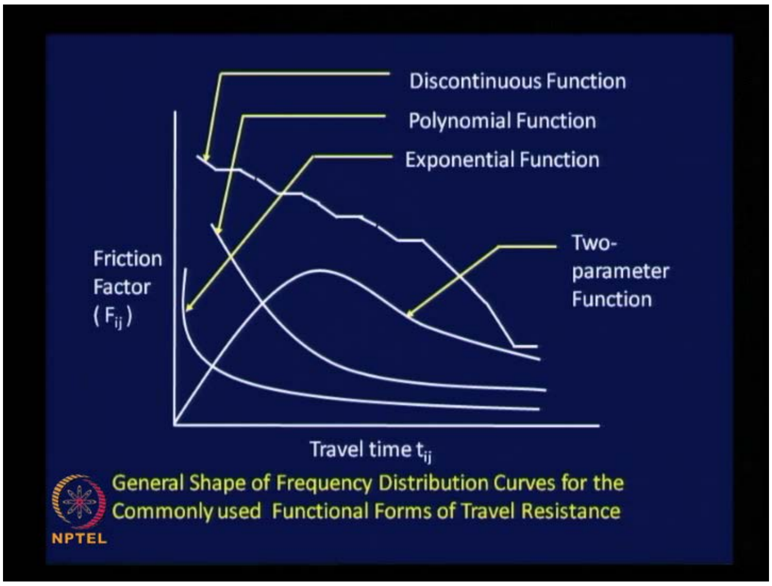

Let us take travel time in x axis, in the F i j value in y axis and if you take the first one polynomial function this will be the variation of F i j value. Generally F i j will decrease with increase in travel time and the other function negative exponential will have this shape, similar trend but, slope will be streak at the initial values of T i j and then to the most similar to the previous one. This is a two parameter function which will increase initially reach a maximum and then decrease subsequently and the and the BPR method will result in this kind of curve, broken curves that means each is will have a different functional form parameter value will be different for different stretches.

So, the slope of this bits of lines vary depending up on the travel time range in which it is falling clear. So, this is how the friction factor as to be determined you may wonder, why not take T i j itself as F i j, why should we express F i j as a function of T i j can you answer this question? Why not simply take T i j as F i j why expressing F i j as function of T i j, because in practice it is found at distribution cannot be explained by travel time alone it has to be a function, that is only reality is that so these are all empirical solutions made based on field observations right, you cannot explain trip distribution simply using directly the travel time between zonal pairs, you need to express it in the form of some function of T i j and this is the general shape of frequency distribution curves for the commonly used functional forms of travel resistance or travel impedance between zones.

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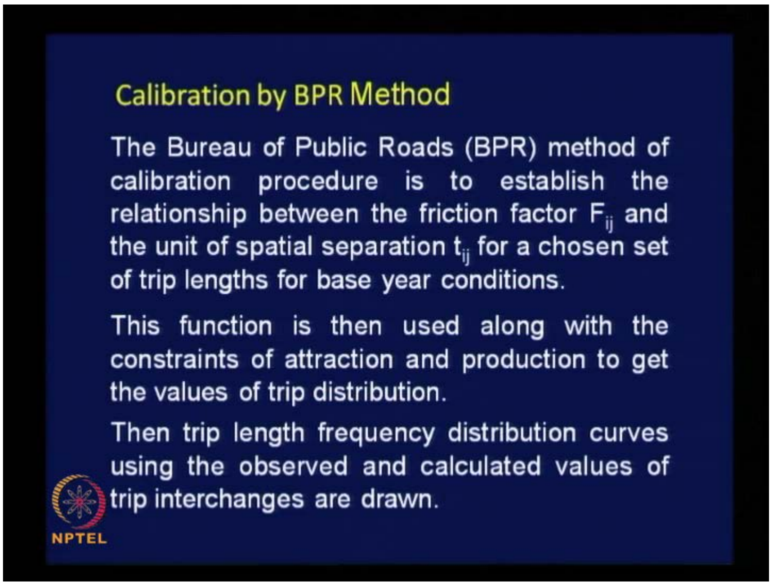

Now, with this understanding let us look into the details of calibration procedure as recommended by the bureau of public roads, which is most commonly adopted as of now, because of the reason that assuming the single functional form for any travel time is not working well in practice. So there is a need to have different functional forms based on your travel time implication, that is why BPR method is used in most cases, the procedure the procedure aims at the establishing the relationship between refraction factor F i j and the unit of spatial separation t i j for a chosen set of trip lengths for a chosen set of trip lengths as I indicated earlier chosen set could be 0 to 2 kilometers 2 to 5 kilometers, 5 to 10, 10 to 15, 15 to 20, 20 to 25 and so on, that is how you need to understand chosen set of trip lengths kilometers or the corresponding travel times right.

So, 3 minutes of travel time 3 to 6 minutes, 6 to 10 minutes, 10 to 20, 20 to 30 and so on right, this function is then used along with the constrains of attraction and production to get the values of trip distribution constraints of production attraction we have distance about so we need to see that we P i and A j values match finally, and we do base iteratively. Then trip length frequency distribution curves trip length frequency distribution curves trip length frequency distribution curves trip length frequency distribution curves using the observed and calculated values of trip interchanges are drawn what we understand the trip length frequency distribution curves or how do you understand trip length frequency, let us hold the curves for the time being, what do you understand by trip length frequency.

Let's say we are segmenting trip based on travel time as trips from 0 to 5 minutes, 5 to 10 minutes, 10 to 15 minutes, 15 to 20, 20 to 30, 30 to 40 and so on, that is a segmented trip length, what is frequency? Number of trip falling over that trip length segment is a frequency is it not right, frequency is nothing but, the number of observations pertaining to a particular identified condition isn't it we are fixing the travel time range 0 to 5 minutes, over the entire urban area you can find out how many trips are falling in this particular travel time range is it possible are not; you have the data for the Bezier condition you would have collected data about the trip made by households right between traffic zones and the travel time involved everything will be known to us mode used information is with us. So that, pool of data it is possible to pick out the trips pertaining to this range travel time falling between 0 to 5 minutes right

Total number we can get right, that number is nothing but, the frequency corresponding to that particular range of travel time or particular range of trip length clear and when you plot relating the number of trips following in each of the range and the ranges you get trip length frequency distribution curves clear.

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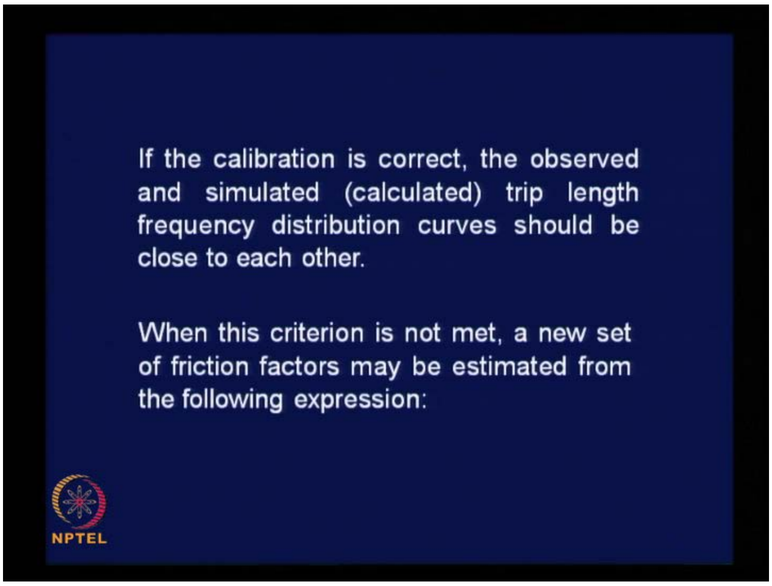

Now, so you draw the curves and if the calibration is correct the observed and simulated or calculated using gravity model is it not, Trip length frequency distribution curves should be close to each other we have the observed values of trip length frequency, then we are going to distribute the trips using gravity model. After distribution, you can get the numbers corresponding to each of the trip lengths, because for each trip length, you are going to have a different function.

So, we will have the total number of trips right on the same set of axis you make both the plots one pertaining to the observed values, the other one pertaining to the model simulated, or the values that your are obtained using the gravity model right and if your assumed functional form for the friction factor is correct right, then the curve pertaining to model value will be very close to the observed the curve pertained to the observed values, with the curve pertaining to the actual field observed values. When this criterion is not met, of course they are not matching with one another, a new set of friction factors may be estimated if they are not matching the reason is obvious our friction factor assumption is not accurate it is not really replicating the field observed trip distribution pattern change your functional form.

Get a new F i j value and then distribute the trips using gravity model with that F i j value right, please note here a new set of friction factors, set means set pertaining to each travel time block we are going to change and then redo the whole exercise.

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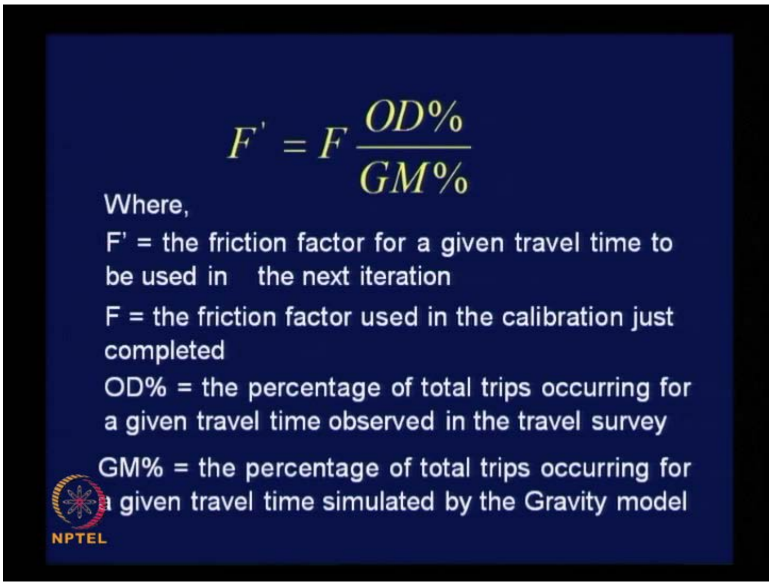

And once you get the a calculated as well as field observed values you should do some modification for this second iteration, that iterative procedure as to follow this correction procedure as we did in the case of correction for adjustment values not adjustment attraction values in the case of trip distribution right. Here F dash is a friction factor for a given travel time to be used in the next iteration, we finish one iteration made the plat pertaining to gravity model as well as the observed data found that, the curves are not matching satisfactorily we are now proceeding with the second with this correction procedure. F is a friction factor used in the calibration just completed, OD percent is the percentage of total trips occurring for a given travel time observed in the travel survey this is observed trip length frequency expressed in the form of percentage of the total, OD percent is nothing but, observed percentage of the frequency pertaining to a particular trip length and GM percent is the gravity model percentage, you get from your gravity model application the percentage of total trips occurring for a given travel time simulated by the gravity model.

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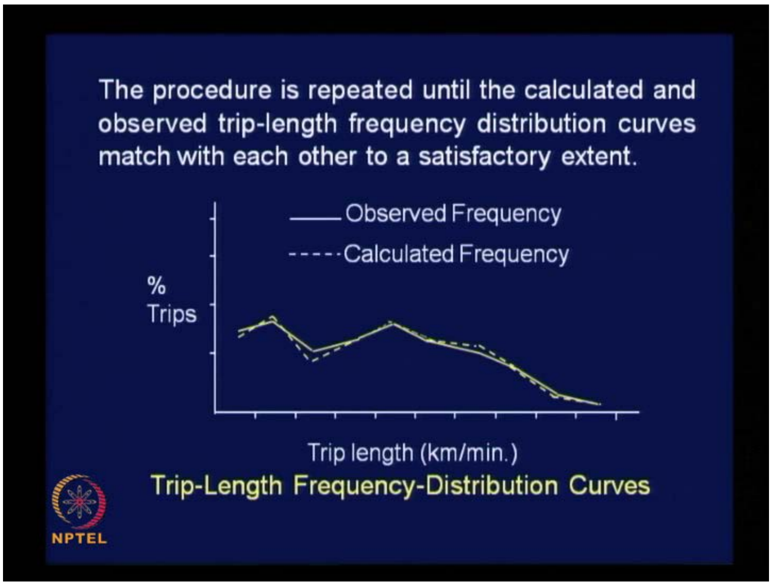

So, get a new friction factor value and apply that for the second iteration and continue the process, the procedure is repeated until the calculated and observed trip length frequency distribution curves match with each other to satisfactory extent right, this is the frequency distribution curve. Trip length very rarely taken as kilometer F everything is same for the entire network, then probably you can accept travel distance if the way vehicle control system terminally everything is same over the network, then then they may not much of variation you can take either distance or time but, mostly it is time to make that point clear I have put both kilometer as well as minute, train for trip length and percentage of trip made is given along y axis, please note this is the range of trips falling over one trip length segment it could be 0 to 5 minutes right.

Let us say we observe certain number of trips falling in this time range and where do we fix that number in the graph, that number correspond to this point this point is at the middle of this range, because it is a representative number for the entire range it should not pertain to the dividing lines here, on x axis it should be at the middle of the range. Similarly, the number of trips observed to be falling the range of trip length of 5 to 10 minutes, should be plotted mid way between these two points here, that is how you get connection between these two points and the curve is plotted like this, that is a point to be remembered carefully; not exactly to the n points it is to the mid values clear. And you see here, the observed value is given by unbroken line and calculated frequency broken line there is some match this is just an example given and it is up to the planner to desire whether to proceed further with iterative procedure or stop at a particular stage, its physical verification of matching of the two curves but, with the experience you can easily understand that understand or fix the stage at which will be able to stop iterative procedure, if we continue with that procedure in any iterative process you may have a point of convergence and then divergence if we go on iterating you will find that you will reach a point of convergence.

If you continue further the error may increase the overall cumulative error may increase from that, you can fix the point of convergence and stop your reiterative procedure do you agree with the statement or not? If you do the iterative process in any case you will touch a point of convergence and if you continue further there will be divergence again so, you will be able to fix the point at which will be you have to stop, that is possible.

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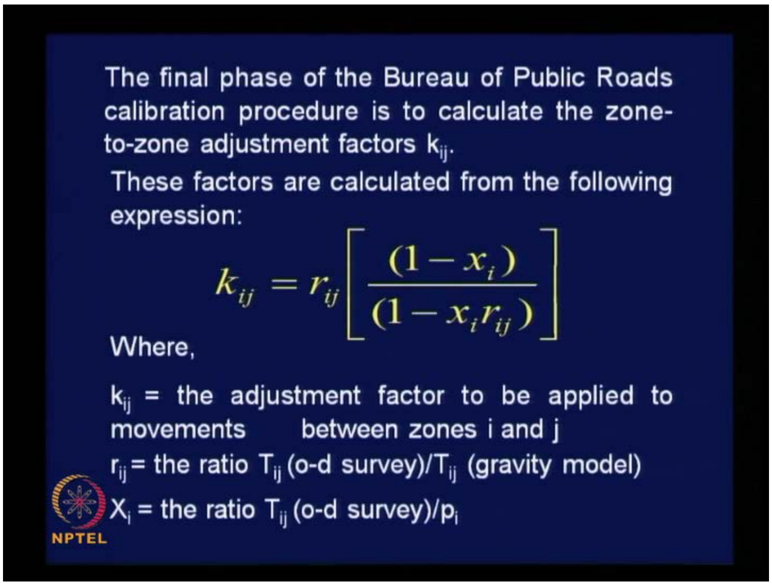

The final phase of the bureau public roads calibration procedure is to calculate the zone to zone adjustment factor K i j, you may recall we talked about K i j. K i j has to be used where there are some special effects which makes the trip attraction or trip distribution between zonal pairs to be totally different from the normal value of trip distribution.

Examples I have given you earlier, a public sector undertaking fixing a factor in one zone and putting all the employees in another zone and if you look at the distribution of trips large number of trips will be distributed between this particular zonal pair. So this may not be matching with the, a normal pattern of trip distribution that you observe for the whole of the urban area.

So, explain this only we talked about zone to zone adjustment factor to take care of the variation in the socio economic characteristics or the connectivity between the zonal pairs based on socio economics characteristics. The procedure recommended by BPR is this you can calculate K i j to be r i j multiplied by 1 minus x i whole divided by 1 minus x i r i j and K i j is a adjustment factor to be applied to movements between zones i and j; this implies that K i j will have different values for different zonal pairs right k 1 2 will be different from k 1 3, k 1 4 and so on right.

r i j is the ratio of T A j based on o d survey or observed you can say T i j o d survey divided by T i j gravity model, are you able to appreciate the logic of getting the ratio r i j as ratio of observed trip interchanges and model estimated trip interchanges between the zonal pair, we do this because of variation between the observed value of k j and model simulated value of K i j. Obviously both have to be bought together do some correction and get some correction factor in the form of K i j and x i another interesting factor is equal to the ratio of T i j observed divided by P i observed again, the production value trip production value of zone i and T i j as we observed in the field from it to other zones you may wonder why should we have the production value clear in this equation. The only explanation is that BPR has obtained this formulation based on number of field studies conducted in the U S, they have done lot of iterations involving all the involved variables and finally, found that, this is best way of accounting for special connectivity between zonal pairs, because of socio economic factors which are different from the normally observed connections between zonal pairs.

You can take this as an empirical formulation pertaining to U S condition, because it has an recommended by BPR and of course, we can try this formulation for our conditions and probably it is a interesting research problem and if you some you are interested you can check whether the K i j are recommended by BPR can be applied for Indian condition if not hat is a modification to be brought into to suit our situation right. We will stop here to summarize what we have seen so far, we were at the middle of doing a numerical example in the application of the gravity model when you started the class, we understood the iterative procedure involved in the application of gravity model and we also appreciated the way the trip attraction values are adjusted at each iteration level and finally, the possibility of getting the right expecting value of trip interchanges in the matrix and we also found that, it is also possible to get the whole numbers which are more logical for all the cells in the matrix which resulted in the whole numbers for trip attraction values also right.

Then, we discussed about the calibration procedure for the gravity model, this basically implies getting some value for F i j in the gravity model and there are different possibilities of getting the value of F i j the normal procedure is expressing F i j as a function of travel time, because distribution is normally done based on more used for travel and there are different possible function forms and we have to choose an appropriate functional form depending upon the data available as well as other field conditions but, BPR bureau public roads USA has recommended a different approach. They have recommended different functional forms based on trip length expressed in terms of a travel time and the BPR calibration procedure is an iterative procedure providing for modification of the friction factor value, if they observed trip length frequency distribution curve and the model simulated trip length frequency distribution curves are not matching and BPR is also recommended a formula with this empirical to get the value of zone to zone adjustment factor, namely K i j. So, with this, we will stop for today and continue with the rest of it in the next class.