Urban Landuse and Transportation Planning

Prof. Debapratim Pandit
Department of Architecture and Regional planning
Indian Institute of Technology – Kharagpur

Lecture – 24
Accessibility - 2

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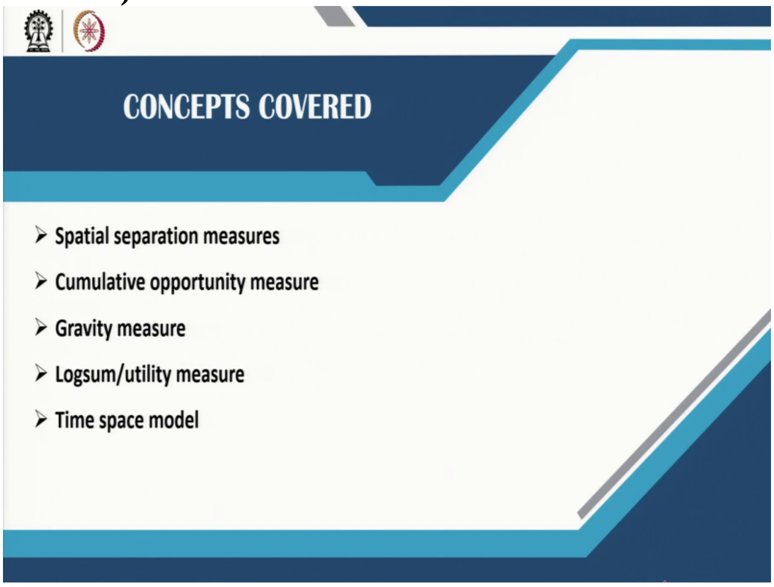

The different concepts covered in this lecture are spatial separation measures, cumulative opportunity measures, gravity measures, log sum utility measures, and time-space model. These are the different ways in which accessibility measures have been categorized. Many scholars, researchers have developed different forms of equations that have been used to generate these kinds of measures.

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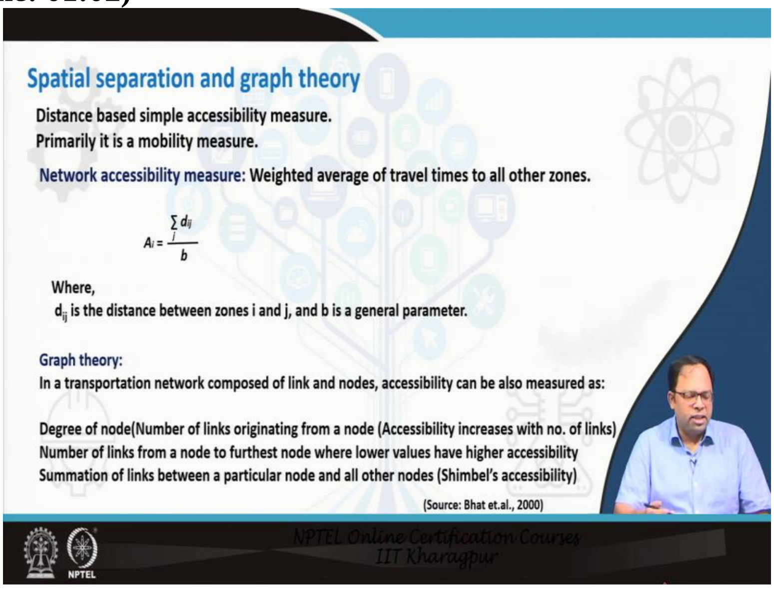

Spatial separation and Graph theory

Spatial separation measures are more or less related to graph theory. It is a distance-based accessibility measure. Also, it is a mobility measure, and it primarily depends on the transportation or the travel times.

So, it can be called a network accessibility measure, where the weighted average of travel times to all other zones is used to determine the accessibility of a particular zone. It is given by the following equation;

$$A_i = \frac{\sum_j d_{ij}}{b}$$

Where Ai is the accessibility of zone i, and dij is the distance between zones i and j, and b is the general parameter. So, Ai is equal to the summation of d ij that means from zone i to all zones j.

This is the general formulation of the network accessibility measure or the spatial separation measure, which is closely related to graph theory. In a transportation network which is composed of links and nodes, accessibility can be also measured as a degree of nodes (number of links originating from a node and accessibility increases with the more number of links), and then the number of links from a node to the furthest node (where lower values have higher accessibility), and then the summation of links between a particular node and all other nodes (which is developed by Shimbel and called as Shimbel's accessibility measure). So, here the structure of the network is considered i.e. the number of links and the arrangement of the links and nodes, some measures of accessibility for each node can be developed.

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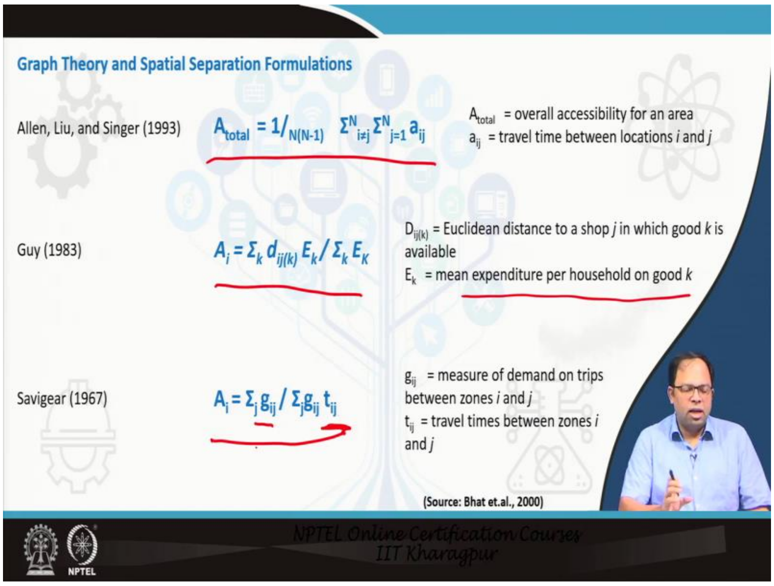

So, other researchers have also developed different forms of this particular measure. Allen, Liu, and Singer have developed this particular form;

$$A_{total} = \frac{1}{N(N-1)} \sum_{i \neq j}^{N} \sum_{j=1}^{N} a_{ij}$$

where A_{total} is the overall accessibility for an area, aij is travel time between location i and j. The factor N (N – 1) is introduced to normalize the values. So, A_{total} is equal to a summation of all the travel time between locations i and j, and then dividing it with the normalizing factor.

In 1983, Guy has given the following form;

$$A_i = \frac{\sum_k d_{ij(k)} E_k}{\sum_k E_k}$$

where he proposes dij of k is Euclidean distance to a shop j in which good k is available, and Ek is the mean expenditure per household on goods k.

He developed the form which primarily determines accessibility to different forms of goods. Since people go shopping for different things at different distances or different locations. Accordingly, general formulation is not a uniform measure of accessibility. It is categorized i.e., the distance for each kind of trip for buying each kind of goods is measured separately and summed up.

Then, Savigear has also shown the accessibility in this particular form;

$$A_i = \frac{\sum_j g_{ij}}{\sum_j g_{ij} t_{ij}}$$

Where gij is equal to the measure of demand on trips between zone i and j, and tij is the travel time between zones i and j. Travel time is introduced in this accessibility measure and both transportation as well as the opportunities, and the land use components are incorporated. So, this is one form which is a kind of transition between the graph theory spatial separation measures and other forms of measures.

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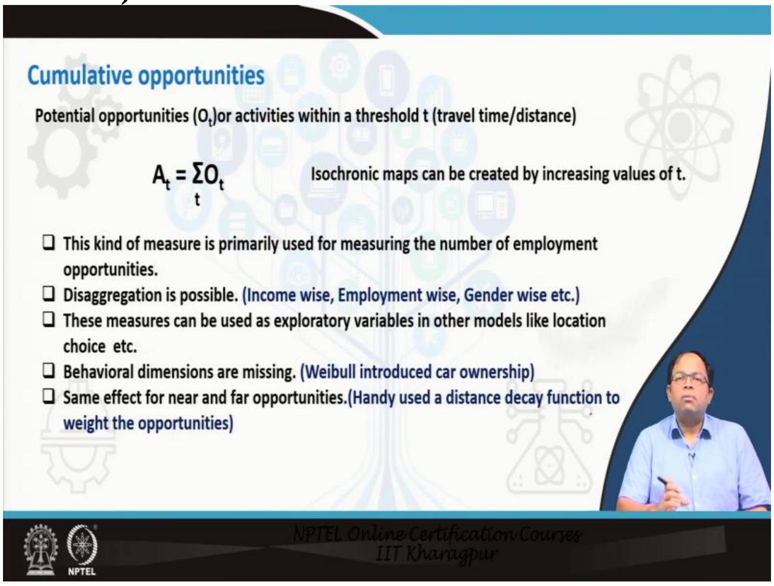

Cumulative opportunities

The next type of measures for accessibility are cumulative opportunities. This measures potential opportunities (O_t) or activities which are available within a certain threshold time (t), that is travel time or distance. Therefore;

$$A_t = \sum_t O_t$$

So, accessibility (At) is equal to the summation of all the opportunities reached within time t. If the t value changes, more opportunities become available. Accordingly, isochronic maps could be created by increasing the values of t. This kind of measure is primarily used for measuring the number of employment opportunities. For example, if an individual is looking for a blue-collar job like a technician or a plumber, he is mostly looking at jobs that are near his house. So, in this particular case, this measure can be used to determine how many kinds of such opportunities are present near his residential area/location.

Also, some form of disaggregation is possible in these measures. Disaggregation is based on income, employment type, or gender. For example, some researchers have found that women are more likely to have a job near their location, whereas, men can have a job far away from their location. So, based on gender, separate isochronic maps could be created, to measure accessibility. This measure can also be used as explanatory variables in other models like location choice. In location choice models, people use this kind of measure to determine what opportunities are there around.

This measure only considers the number of opportunities and does not include any behavioral dimensions, like socioeconomic characteristics. Weibull addressed this by introducing car ownership and stated that different people with car ownership, have different accessibilities or cumulative opportunities. The behavioral dimension plays an important role in measuring accessibility.

Additionally, there is the same effect for near and far opportunities in this accessibility measure i.e. it considers opportunities equally. For example, a near local shop and a faraway regional centre (shopping mall) will have the same accessibility because this measure does not take into consideration the effect of travel. Handy (1993) addressed this issue by introducing a distance decay function to incorporate the effect of travel. As discussed in the previous lecture, people perceive no difference between 10km and 12km, when considering far opportunities, whereas they perceive 1 km and 2kms differently when looking for local opportunities. Therefore, the effect of travel is not much for far opportunities but it would be higher in case of near opportunities like local convenience stores.

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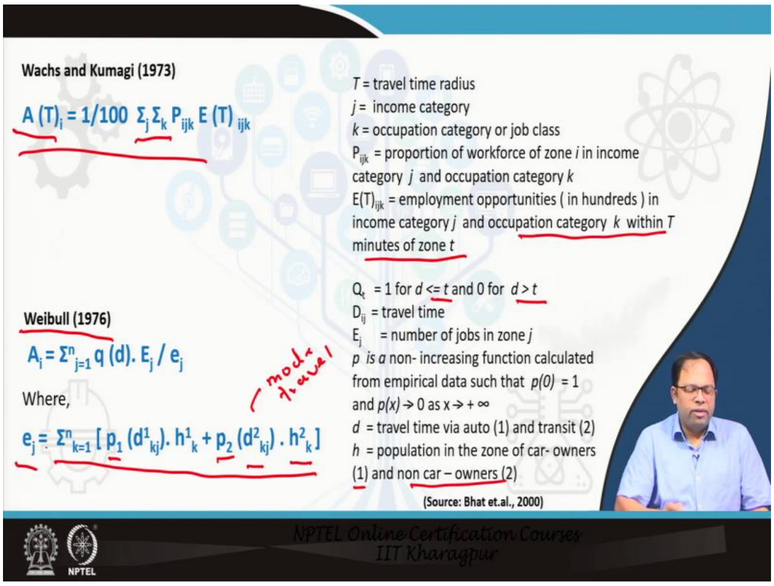

Many researchers have developed different equation forms to measure cumulative opportunities. Some of the forms that are discussed are as follows.

The next form is given by Wachs and Kumagai;

$$A(T)_i = \frac{1}{100}\sum_{j}\sum_{k} P_{ijk}\left(E(T)_{ijk}\right)$$

where $A(T)_i$ is the measure of accessibility of zone 'i', P ijk is the proportion of workforce of zone 'i', in income category 'j', and occupation category 'k'. So, the workforce is subdivided using two variables, income category and occupation category. It is multiplied with employment opportunities (in hundreds) in income category j, occupation category k within T minutes of zone i. Then, it is done for all the groups. In this way, all the jobs (or opportunities) available within a certain distance for a particular group of people are determined.

The second form is Weibull's equation;

$$A_i = \sum_{j=1}^{n} q_t(d_{ij}) * \frac{E_j}{e_j}$$

where;

$$e_j = \sum_{k=1}^{n} [p_1 * (d_{kj}^1) * h_k^1 + p_2 * (d_{kj}^2) * h_k^2]$$

In the first equation, Ai is accessibility for zone i, and dij is the travel time from zone i to zone j, and Ej is the number of jobs in zone j. If d < = t and 0 then qt is equals to 1, and for d > = t, qt is 0.

In the second equation, h_k^1 is the population in a zone for car-owners, and h_k^2 is the population of non- car owners in the zone, and d is travel time via auto (1) or transit (2), and then p is the non-increasing function calculated from empirical data.

So, these are empirical formulas, but in this form, the mode and its travel time is incorporated. So, for each travel time and each mode, the measures are calculated separately and then added up to get the value of ej.

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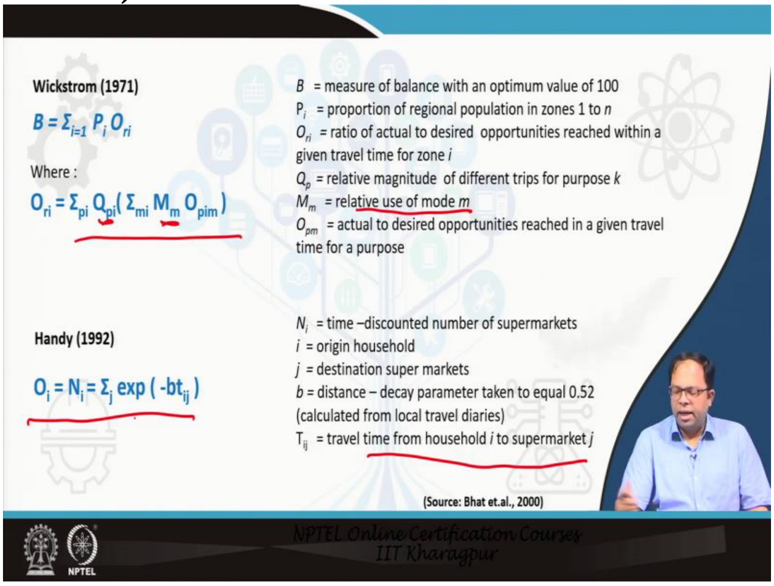

Then Wickstrom (1971) has given the form;

$$B = \sum_{i=1} P_i O_{ri}$$

where B is the measure of balance with an optimum value of 100, P i is the proportion of the regional population in zones 1 to n, and O ri is the ratio of actual to desired opportunities reached within a given travel time for zone i, and it would be measured using the following equation;

$$O_{ri} = \sum_{pi} Q_{pi} \left(\sum_{m1} M_m O_{pim} \right)$$

Now, O pim is actual to desired opportunities reached in a given travel time for a purpose. So, this factor takes into consideration what people want and actually what value they are getting there. Mm is the relative use of mode m, and Q p is the relative magnitude of different trips for purpose k.

So this value gives a cumulative measure, where the mode, the total opportunities, and also the total type of trips that are being made, are incorporated. Then, these are summed up and multiplied with the proportion of the regional population.

Handy (1993) has proposed another cumulative type accessibility measure which is;

$$O_i = N_i = \sum_j \exp(-bt_{ij})$$

where Ni is the time discounted number of supermarkets, i is the origin household, j is the destination supermarkets, tij is the travel time from household i to supermarket j, and b is a distance decay parameter which is equal to 0.52, calculated from local travel diaries i.e., based on survey values. So, tij is being weighted by a distance decay parameter so that its effect is different. Also, b value can be different, for example, if this is not for supermarket and measured for some other facility, then the b value could be different.

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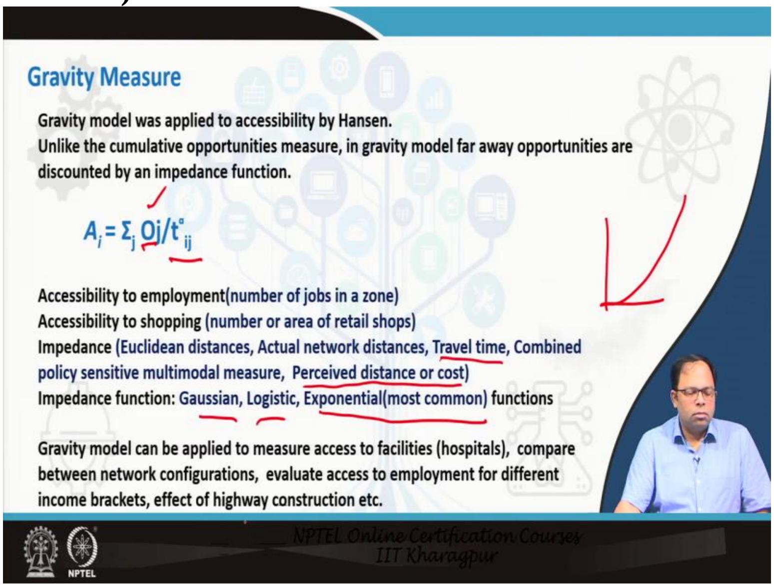

Gravity measure

The gravity model was first applied to accessibility by Hansen. Unlike the cumulative opportunity measure, in the gravity model far away opportunities are discounted by an impedance function. So, the factor t ij is explicitly introduced in gravity measures only.

Even though some researchers have used the travel time function as an impedance, in gravity measure it has to be a part of the equation form. Opportunities are divided by the travel time (or impedance), which means that the far away opportunities results in lower accessibility. So more opportunities results in higher accessibility, and increased distance results in lower accessibility.

So, accessibility to employment or accessibility to shopping (Ai) of zone i can be determined using the following equation;

$$A_i = \sum_j \frac{O_j}{t_{ij}^{\alpha}}$$

Where Oj is the number of jobs or number/area of retail shops respectively, and t_{ij}^{α} is an impedance function. Impedance can be measured by Euclidean distances i.e. straight-line distances, or actual network distances i.e., the actual distance along a particular route network or a road network. It could also include travel time, or a combined policy sensitive multimodal measure. Since travel time is an average measure between two points, based on the mode used, this travel time changes. So a combined policy-sensitive multimodal measure including the travel time by different modes are taken, and the cost/time for each mode can be added. Another measure of impedance can be perceived distance or cost.

The impedance function can be a power function, a Gaussian function, a logistic function, or an exponential function. The exponential function is the most common form for this particular impedance function where distance is discounted exponentially.

Gravity type accessibility measures can be applied to measure access to facilities, such as hospitals. For example, when a land use for an urban area is designed, the allocation of land use in different areas is decided. So, a particular plan is proposed and this plan is evaluated. Now, to evaluate this plan, gravity measures for different zones can be calculated to determine the accessibility. Similarly, accessibility can be calculated for facilities. If a hospital is located in a certain part of the city, and the accessibility to this hospital is low from some zones then it has to be addressed. To do so, more hospitals in other areas can be provided, or that particular hospital can be relocated. Gravity measures can also be applied to compare between network configurations. It can be used to infer that which network structure is more effective, or which one provides low accessibility.

Additionally, access to employment for different income brackets, or the effect of highway construction and many other things can be evaluated using this accessibility measures.

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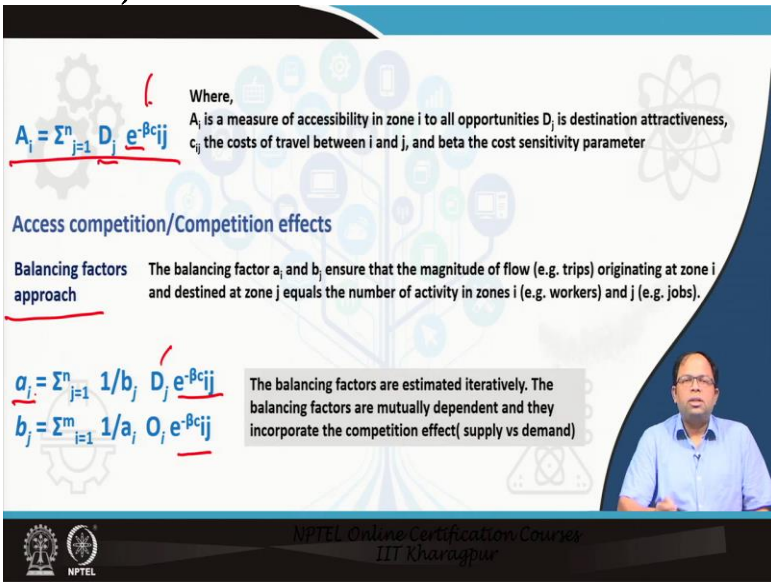

The most common form of this accessibility measure is;

$$A_i = \sum_{j=1}^{n} D_j e^{-\beta c_{ij}}$$

where Ai is the measure of accessibility in zone ‘i’ to all opportunities Dj which is destination attractiveness, c ij (impedance) is the cost of travel between zone ‘i’ and zone ‘j’, and β is the cost sensitivity parameter. β value is to be calibrated based on actual data. Also, j = 1 to ‘n’ means, all zones, which are accessible from this zone ‘i’.

If a demand for a particular opportunity increases in other zones, then automatically the accessibility for that zone that we are measuring decreases. This is known as access competition or competition effects. To determine what effect other zones have, the total amount of demand and the total amount of opportunity needs to be balanced. So, this is called a balancing factors approach. So, two balancing factors ai and bj are introduced which ensures that, the total magnitude of flow/trips originating at zone ‘i' and destined at zone ‘j’ equals the number of activities in zone ‘i’ (e.g. workers) and ‘j’ (e.g. jobs). Once it is formulated then it is done for all zones and it is checked that the total number of trips originating in one zone is actually ending(suppose for a job) in another zone. So, this is similar to balancing of a gravity model.

The balancing factor ai and bj can be measured as follows;

$$a_i = \sum_{j=1}^{n} \frac{1}{b_j D_j e^{-\beta c_{ij}}}$$

$$b_j = \sum_{i=1}^{m} \frac{1}{a_i O_i e^{-\beta c_{ij}}}$$

where, Dj is the destination attractiveness, and Oi is the total number of origins, and e^(-βc_{ij}) is the impedance function. This ensures that the total number of trips that are originating, are also ending. In the first step, the values are estimated, and then it is done iteratively one after another. When there is not much change in the values of the balancing factor after each iteration, these are adopted as the final values. In this way, the competition effect is taken into consideration.

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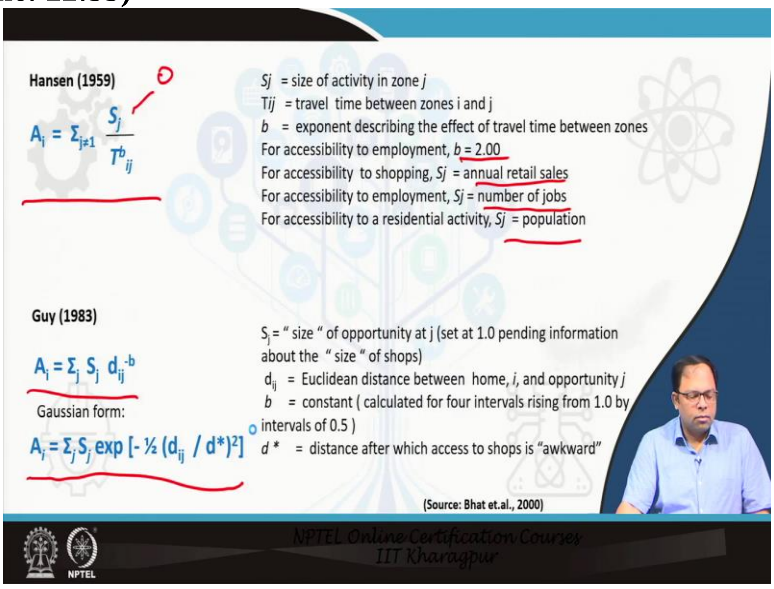

Many authors have developed a different form of gravity type accessibility measures. For example, Hansen has developed the following equation;

$$A_i = \sum_{j\neq1} \frac{S_j}{T_{ij}^b}$$

where Sj is equal to the size of activity in zone j, and T ij is travel time between zones i and j. b is the exponent describing the effect of travel time between zones. He estimated b=2 for accessibility to employment. Now, depending on the context for which accessibility is to be determined, he considered Sj measures. For example, for accessibility to do shopping, S j becomes annual retail sales, for accessibility to employment, S j becomes number of jobs, and accessibility to residential activity, S j becomes population.

In 1983, Guy proposed a particular form, which is;

$$A_i = \sum_j S_j d_{ij}^{-b}$$

where Sj is the size of opportunity at j, and d ij is the Euclidean distance between home i and opportunities j, and b is a constant. People have calibrated and have set values for this b as per the data set that they have got. Also, another form i.e. Gaussian form was given.

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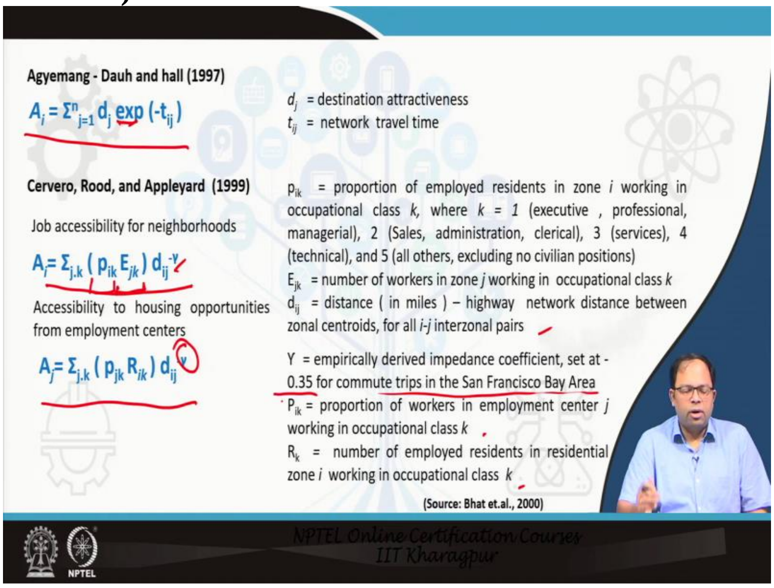

Agyemang, Dauh, and hall (1997) have measured accessibility using the following form;

$$A_i = \sum_{j=1}^{n} d_j \exp(-t_{ij})$$

where dj is the destination attractiveness, t_{ij} is the network travel time, and this formulation uses an exponential function.

Cervero, Rood, and Appleyard have formulated a measure for job accessibility and housing accessibility. These can be written as:

$$A_i = \sum_{j,k} (p_{ik} E_{jk}) d_{ij}^{-\gamma}$$

$$A_j = \sum_{j,k} (p_{jk} R_{ik}) d_{ij}^{-\gamma}$$

Ai is the job accessibility for the neighborhood, whereas Aj is accessibility to housing opportunities from employment centres. Residents are categorised into different occupational classes i.e. k = 1 (executive, professional, managerial), k = 2 (sales, administration clerical), k = 3 (services), and so on.

Considering job accessibility, Ejk is the number of workers in zone j working in occupational class k, and dij is the distance or highway network distance between zonal centroids for i j interzonal pairs.

Similarly, residential or housing opportunities are calculated, where pjk is equal to the proportion of workers in employment centers j working in occupational class k, and Rk is the number of employed residents in residential zone i working in occupational class k. Thus, workers in the different employment centers are distributed to the different residential zones.

Y is an empirically derived impedance coefficient set at -0.35 for commute trips in the San Francisco Bay area. So, this is the calibrated value of this factor considering this particular function, based on the data set that have been used. If accessibility measure is developed for another city, then the model needs to be calibrated as per the local data.

Thus, gravity models can be used for different groups of residence or different purposes. Accessibility for different groups can be calculated seperately and then added up to determine the overall accessibility for a particular zone.

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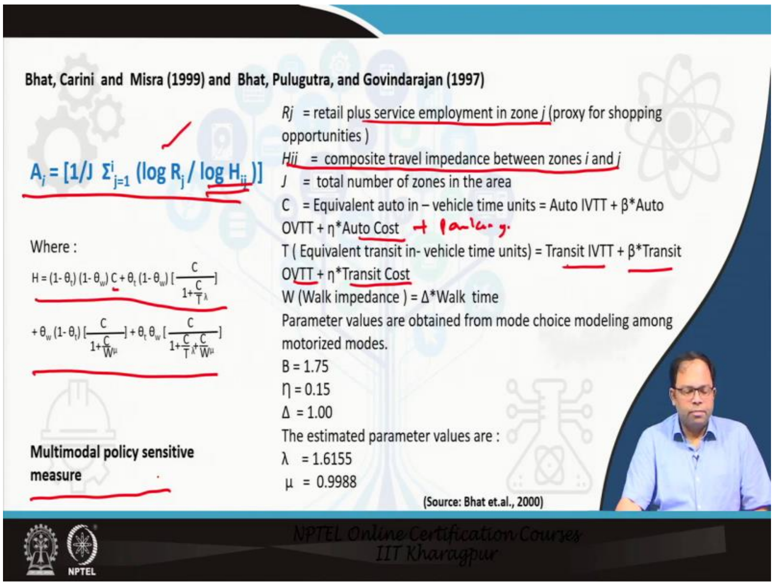

Finally, Bhat, Carini, and Misra (1999), and also Bhat, Pulugutra, and Govindarajan (1997) have developed a measure which is illustrated in the above slide. This is a simple measure, only a composite term (Hij), which includes the travel time, travel cost, and the mode, has been used.

T is the equivalent transit in-vehicle time which includes transit in-vehicle time, transit out of vehicle time and transit cost. Then, C is equivalent auto in-vehicle time, which includes auto in-vehicle time, auto out of vehicle time and auto cost.

When an individual chooses a mode, travel time is a big parameter that influences mode choice. Travel time can be broken into in-vehicle travel time which is the time spent within the particular vehicle, then the access time which means the time taken to go to the parking to get the car, and for transit, one has to walk to the stop, and then waiting time at the stop.

In the formulation, H ij is the composite traveling impedance value between zone i and zone j, and Rj is the retail plus service employment in zone j which is a proxy for shopping opportunities since shopping accessibility is being measured.

The reason for introducing so many variables is to test policy effects. Whenever in a city a policy is introduced or a change is implemented, it becomes important to understand what effect it can have on the accessibility. For example, a policy related to increasing parking costs in a particular zone of an urban area. When the parking cost increases, it will reduce the accessibility of this particular zone because the total cost for the car will increase due to the inclusion of parking costs. Additionally, if the number of bus stops are increased then it will reduce the OVTT, which means one has to walk very little to reach the bus stop. Thus, if the number of bus stops in the city increases, then it will increase the accessibility. Thus, different policies that affect accessibility are included in the equation to test the effect of that policy. These are multimodal policy sensitive measure for the gravity model.

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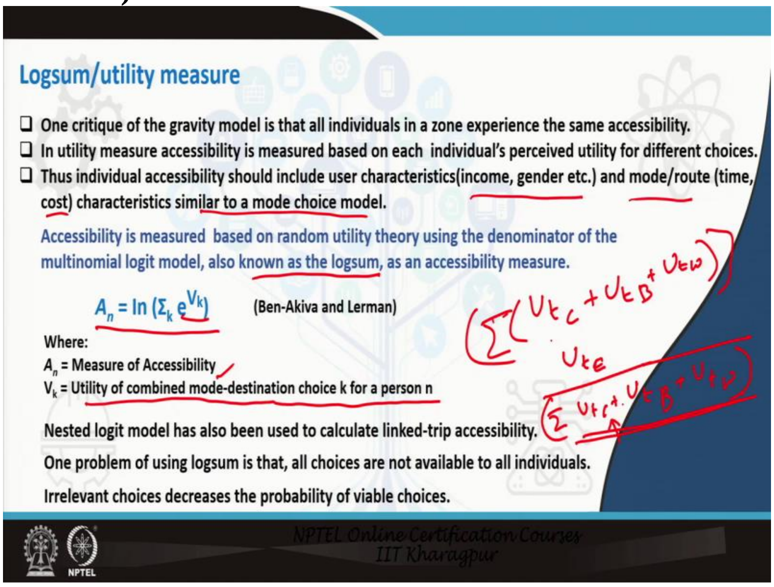

Logsum/utility measure

In addition to the gravity model, another accessibility measure is the logsum or utility measure. This was developed to overcome the major critique of the gravity model. The gravity model assumes that all individuals in a zone, even though these individuals are categorized into employment categories, or based on income categories, experience the same accessibility, but it is not true.

Different people experience accessibility in different ways. In utility measure, accessibility is measured based on each individual's perceived utility for different choices. Utility is the benefit that a person can derive from a particular choice. This choice could be for a mode, a location, and so on. So, an individual compares multiple options and then chooses the opportunity which has got the highest utility.

Utility measures are based on many variables. It can be based on personal characteristic like income or gender. Different people may perceive utility in a different way. For example, if an individual has money, he will be insensitive to cost, so increasing the bus fare will not have any effect on him. This measure can also be based on the characteristics of a particular mode like time/ travel cost. Therefore, all these different characteristics or behavioral measures can be incorporated while developing this kind of measure. This is where the utility measures differ from a standard gravity measures.

Accessibility is measured, based on random utility theory, using the denominator of a multinomial logit model also known as the log sum. For example, there are three modes of travel in a particular area (car, bus, and walk). Each mode has got a utility value i.e. Ut_{car}, Ut_{bus}, and $Ut_{walk.}$ When the accessibility from a particular zone is calculated as the summation of all the utilities for different modes i.e. (Ut_{car}+ Ut_{bus} +Ut_{walk}). The probability of choosing a mode from a set of available modes will be equal to the utility of that particular mode divided by the summation of the utility of all available modes. A logit model is a way to derive this probability, and the multinomial logit model is a variant of the logit model when more than two choices are involved. So, the probability that a person will choose a car becomes;

$$\frac{U_{tcar}}{U_{tcar} + U_{tbus} + U_{twalk}}$$

This denominator value is called the logsum. So, logsum is a combined utility of all the modes that could be considered.

Ben Akiva and Lerman proposed the following form to measure accessibility;

$$A_n = ln\left(\sum_k e^{V_k}\right)$$

Where A_n is the measure of accessibility, and Vk is the utility of combined mode-destination choice k for a person n. They developed an accessibility measure based on the joint choice of mode and destination. There can be different kinds of joint choices, each one with different utility, which can be used to measure accessibility. But, joint choice models are more advanced models.

It is important to mention that all choices are not available to all individuals. So, irrelevant choices may decrease the probability of viable choices. For example, a person may not have access to a car because he does not have a car. He has only access to the bus and walking. So, if the utility of a bus or walking is divided by logsum then it will probably give wrong results. This is the major issue with logsum. Nested logit models are used to address this issue.

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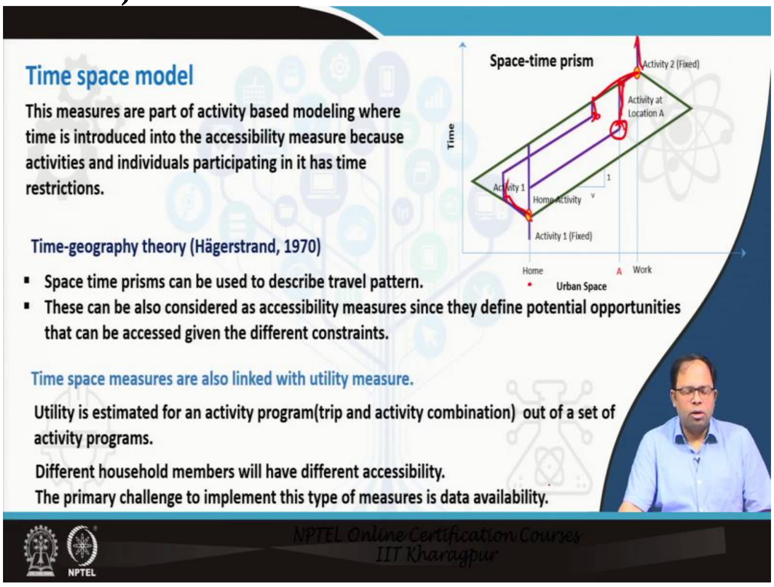

Time space model

This measure is part of activity based modeling where time is introduced into accessibility measure because activities and individuals participating in it has time restrictions. It means that a person can only participate in a particular activity if he has time for it. In this measure, a space-time prism is created by describing a person’s trajectory or travel pattern. A point in this prism represents an individual with coordinates (x,y,z), where location is given by (x,y) and time is the third dimension (z). In the figure given in the slide, a person has two fixed activities at two locations. Activity 1 is carried out at home (x1, y1) and activity 2 is work at location A (x2, y2) and in between he has to go shopping. Each activity requires some time to participate in and time to travel to a specific location. The person can participate in these activities in multiple ways given his time budget. So, he can spend some time at home and then travel to his shopping destination spend time, then go to his office and spend time at his office, or he can spend more time at home, then goes to shopping where he can spend little time for his shopping and then he goes to his office. So in this particular way, the trajectory takes the shape of a prism.

Time space measures are also linked with utility measures. Utility is estimated for an activity program (trip and activity combination) out of a set of activity programs. So, each prism has a different utility score. Because the prism is not tracing the movement of the individual rather it is measuring the total opportunities that are available and time that is available to a particular person within his activity space. Therefore, based on different combinations, he will choose that particular combination which gives him maximum utility.

In the 1970s, Hagerstrand proposed the time-geography theory. He stated that space time prisms can be used to describe travel patterns as discussed above. Also, this can be considered as an accessibility measures since they define potential opportunities that can be accessed using different constraints. For example, an individual has got certain constraints like he has to be at home for a certain time, he has to be at the office at a certain time.

It is important to understand that, this is not like a standard 4 stage travel demand model, which aggregates the number of trips generated from a zone, the number of trips distributed to a particular zone and what mode and route is used for traveling. Instead, it talks about what activities does a person does throughout the entire day, when he chooses to participate in an activity, what time he wants to go there, how much time he wants to spend there, or how he wants to organize his entire days' time. So, this is an activity based approach to travel modeling which is considered in this time space model. Also, different household members will have different accessibility. For example, a person has to go to work at location A while his spouse works at location B. Both have different activity spaces, so both will have different accessibility.

The primary challenge to implement this type of measure is data availability. Because a huge amount of data is required to understand the travel patterns of each individual. Besides, different people, different age groups, gender groups, income brackets, and based on different family structures, people have different travel patterns and choices. This kind of accessibility measures can be also created but these are advanced measures.

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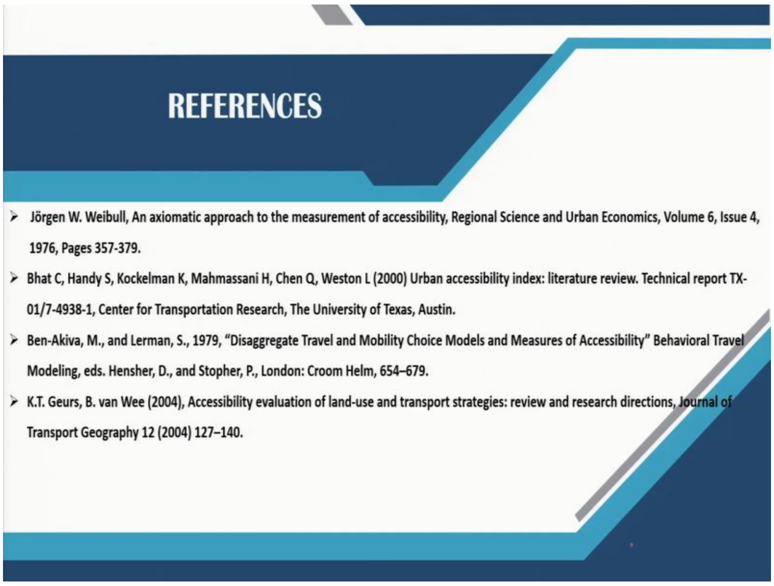

Some of the references are listed in the above slide.

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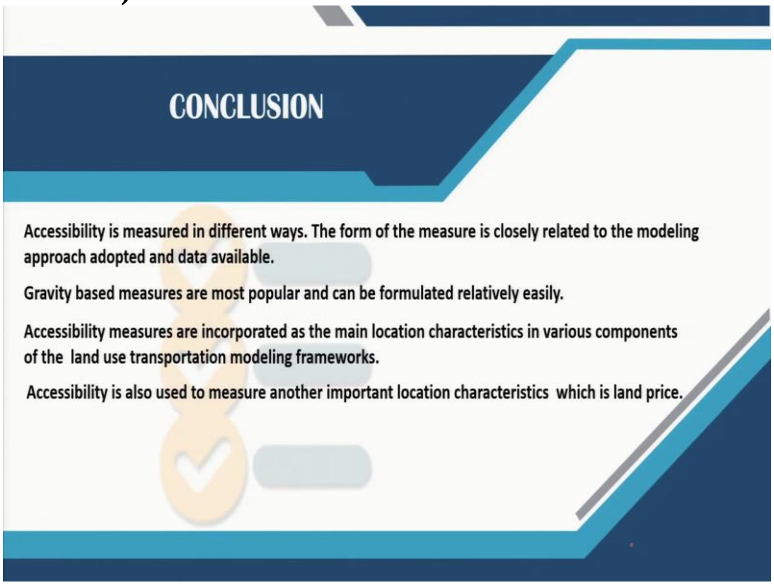

Conclusion

Accessibility is measured in different ways. The form of the measure is closely related to the modeling approach adopted and data available. So, depending on what kind of model is to be developed, the form of measure should be chosen.

Gravity based measures are the most popular measures. It can be formulated relatively easily. Also, accessibility measures are incorporated as the main location characteristics in various components of the land use transportation modeling frameworks. This gives the characteristics of location for a particular area i.e. attractiveness for a particular area.

Accessibility is also used to measure other important location characteristics which is land price.