Urban Landuse and Transportation Planning
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Lecture-08
Modeling Approaches

Welcome back. In this lecture, we will cover the different modeling approaches.

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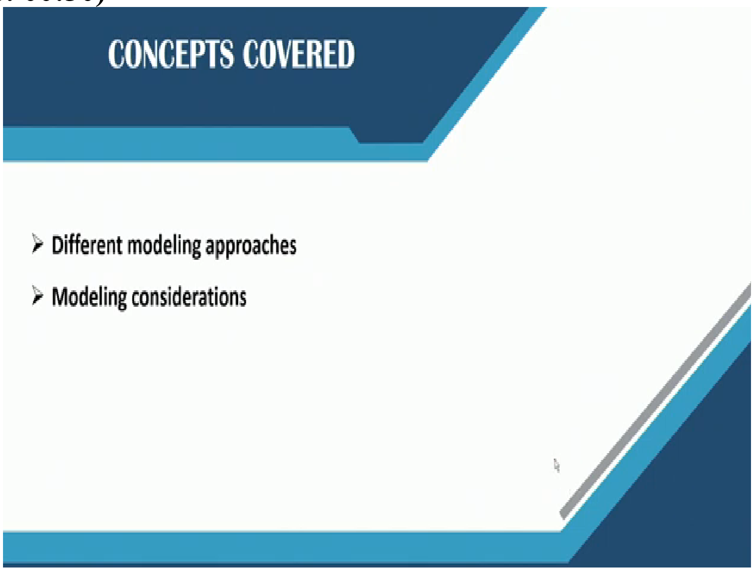

So, the concepts covered are; Different modeling approaches and Different modeling considerations.

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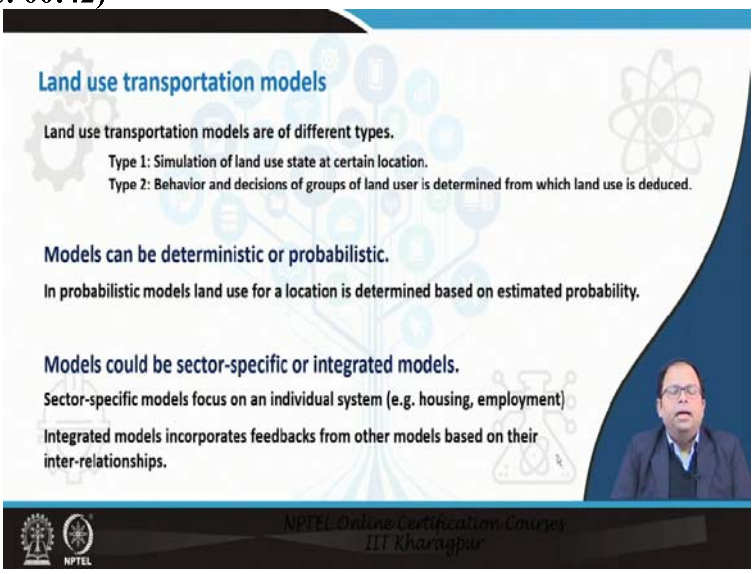

Land use transportation models

Land use transportation models are broadly of two types. The first type is where the land use state of a particular location is simulated i.e., we trace how land use of a particular plot or a particular area changes over time. The second type is based on determining the behavior and decision of groups of land user from which the land use is deduced i.e., from their buying and renting behavior etc.

These models can be both deterministic and probabilistic. In probabilistic models, land use for a location is determined based on its estimated probability. Since it is probabilistic, there is a chance that a person can choose another land/land use. Thus, there has to be a way to allocate a particular land/land use to a particular person which will be covered in a later lecture.

Models can be also sector specific or integrated. Sector specific models focus on an individual system like housing or employment etc. whereas, integrated models incorporate feedbacks from other models based on their interrelationships so that it can update itself over a period of time. Thus, integrated models are more robust compared to sector specific models.

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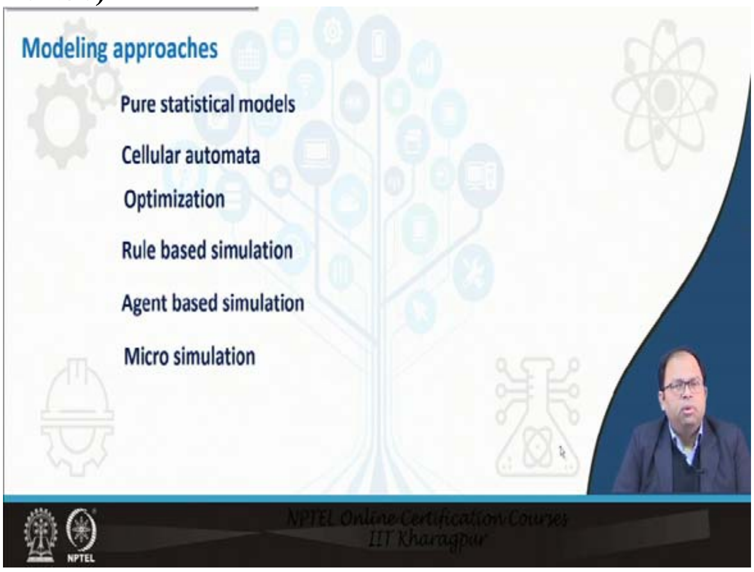

Modeling approaches

The different approaches to modeling of urban land use and transportation can be broadly categorized as pure statistical models, cellular automata models, optimization models, rule based simulation models, agent based simulation models and micro simulation models.

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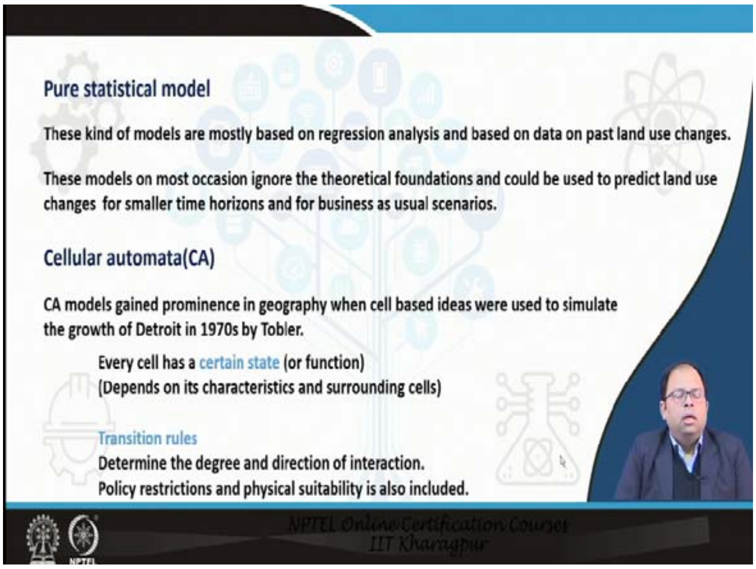

Statistical models

Pure statistical models are based on statistical regression analysis. These models do not necessarily follow any specific theoretical approach like e.g., the location theory or the spatial allocation theory or the social theories and are primarily based on certain hypothesis and assumptions. These models are developed using regression techniques based on past data on land use change. Since, these models lack any theoretical foundation and are based on data patterns from a few or may be just a single previous period they are suitable only for small time horizons and for business as usual scenarios. On the other hand, to understand causality e.g., why people choose certain things or what determines the choice behavior of a particular firm, requires more detail understanding and theoretical basis to avoid wrong predictions.

Cellular automata models

Cellular automata(CA) models were developed within the geography discipline, and are used to predict urban growth, change in form and land use. On the other hand, these models do not have the theoretical underpinnings of urban economic theory which has led many urban planners to criticize these models. Transportation is also not considered in CA models.

CA models initiated by Tobler were initially used to simulate growth in the Detroit urban areas in US during the 1970s. CA models are based on cell based ideas which state that, every cell has a certain state or function and it depends on itself and the characteristics of the surrounding cells.

Next, there are transition rules i.e., cells change their state from their existing state to a new state based on certain transition rules which determine the degree and direction of interaction. These transition rules also consider the policy restrictions and the physical suitability required for the transition process. For example, residences cannot be allotted to an already designated industrial area. Similarly, physical suitability of an area like slope and resulting landslides are considered when a building construction decision is taken.

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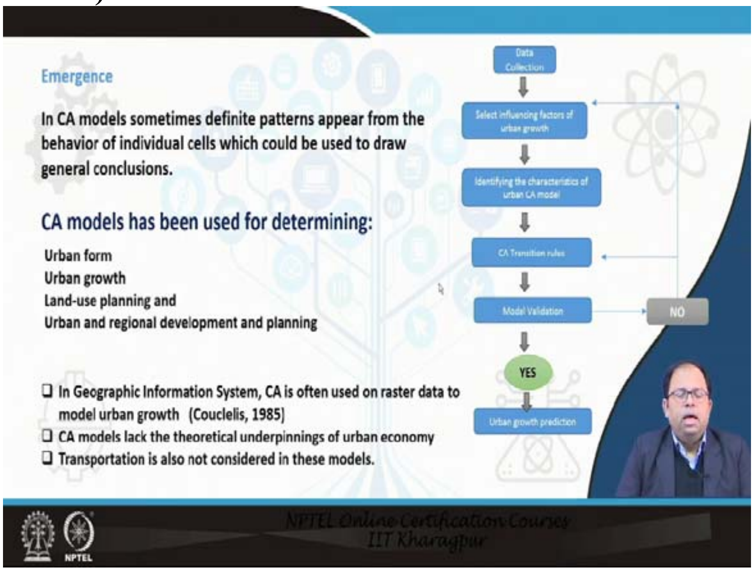

Once transition rules are finalized and the model is simulated, at the end of the model run, some new patterns appear based on the behavior and transition of each individual cell. This is known as emergence and we can draw general conclusions regarding the trends or patterns of change in that particular urban area. Thus, CA models are used for determining urban form, urban growth, land use and also urban and regional development. CA models are often used on raster data to model urban growth along with Geographical information systems(GIS).

The image shows the typical structure of a CA model. A CA model starts with data collection and then factors/characteristics/features are identified for determining urban growth. Next, relevant attributes among these factors are identified which is incorporated within the CA model. Next, CA transition rules are formulated and finally, the model is validated by matching the changes with the actual outcome. The model is modified till it is validated. Validation is done taking old data (10-year-old land use data) and matching the outcome with the present. The validated model can be used to predict future urban land use patterns that could emerge in the upcoming years.

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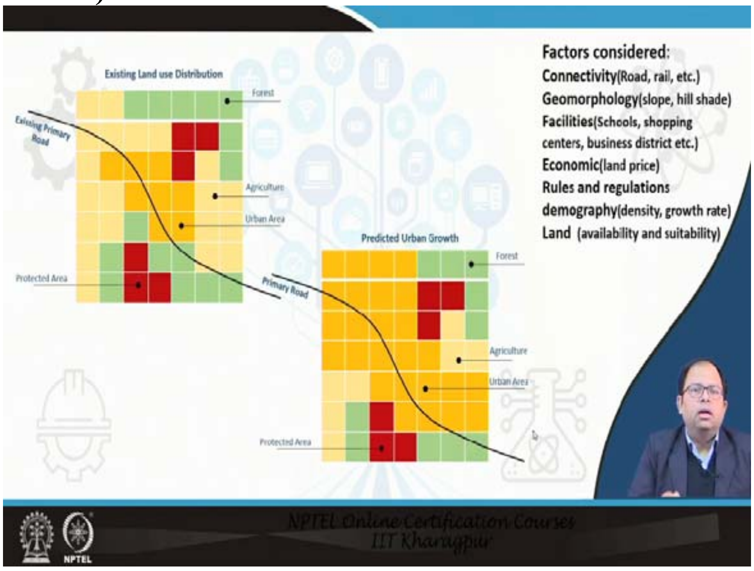

The above image shows existing land use distribution including protected forest areas(brown), forest area(green), agricultural areas (light yellow), urban area (bright yellow) along with a road passing through. Next, several factors are considered like connectivity, the geomorphology (slope, hill shade etc.), presence of school, shopping centers, business district, land price, rules and regulations, restrictions in terms of land use, demographic characteristics (density, growth rate etc.), land availability, land suitability for particular purposes etc. to define the transition rules. Next, cells are allowed to change based on the transition rules. Once transition is complete, some cells are found to remain as they were and some cells have changed. For example, since forest land is protected to certain extent, a lot of forest land(cells) is retained, whereas, most of the agricultural land is converted and particularly the ones in close proximity of a transportation corridor. This is how a CA model predicts the change in a particular urban land use.

CA models cannot be used for prediction of transportation, since they do not include a transportation component. CA models are only valid when existing conditions or existing macroeconomic climate remain same. These are some of the limitations of a CA model.

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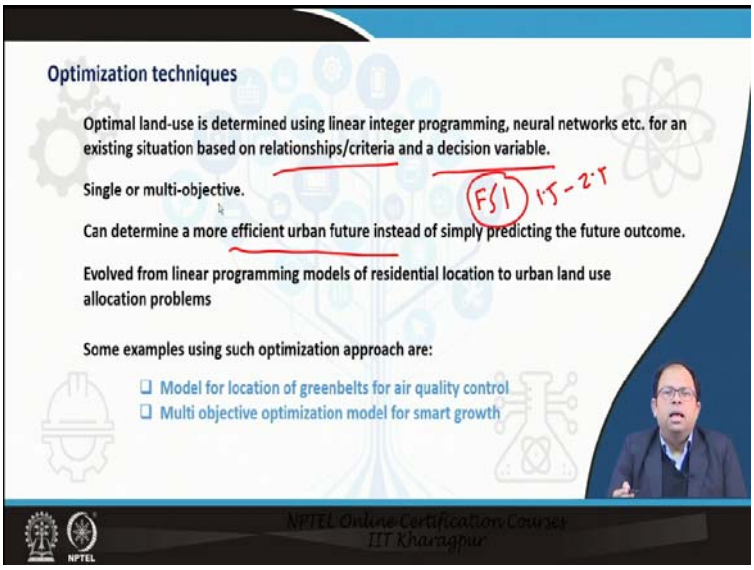

Optimization techniques

Another group of urban land use transportation models are based on optimization approaches where, optimal land use is determined using linear integer programming. A land use situation is optimized based on a decision variable, relationships and criteria and constraints. These models, instead of determining the urban future based on the current trends and choices by individuals or firms, focuses on determining a more efficient urban future. These models actually evolved from the linear programming models of residential location or urban land use allocation which are used for allocating urban land use in the most suitable way. While these models are relatively rare, some examples of this particular approach are, determining locations of green belts for air quality control and multi objective optimization model for smart growth. Optimization models could be either a single objective or a multi objective optimization model.

Density of an urban area can be increased using transit oriented development. If, FSI or density is increased or decreased, then a new land use pattern would emerge. This new pattern could be measured in terms of total transportation cost which means lower the transportation cost the land use pattern is efficient. This land use pattern or in this case transportation cost could be determined using different relationships/criteria and constraints which links FSI/density with the transportation cost. Thus FSI/density can be called the decision variable in this optimization model and lowering transportation cost the objective.

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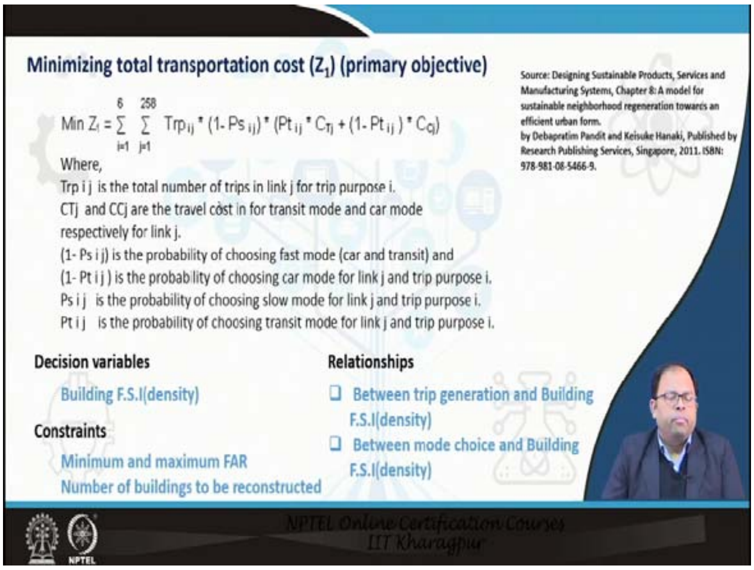

In the above example, the equation lists the primary objective of the model i.e., to minimize the total transportation cost for different kinds of trips. The decision variable is building FSI. Constraints are minimum and maximum FAR that is allowed and the number of buildings that can be reconstructed at a higher density (Developers would always try to utilize the maximum FSI). FSI is linked with transportation cost through different relationships some of which are between trip generation and building density (when building density increases, number of trip reduces or the length of trip reduces) and between mode choice and FSI (when density is high people are more prone to choose certain modes which will lead to lesser cost). Relationships could be either positive or negative. Using these relationships, we can determine the optimum density to minimize transportation cost.

Thus optimization based land use transportation models help us in determining a better/efficient land use and also in specific instances like trying to determine optimum density for transit oriented development for a particular area.

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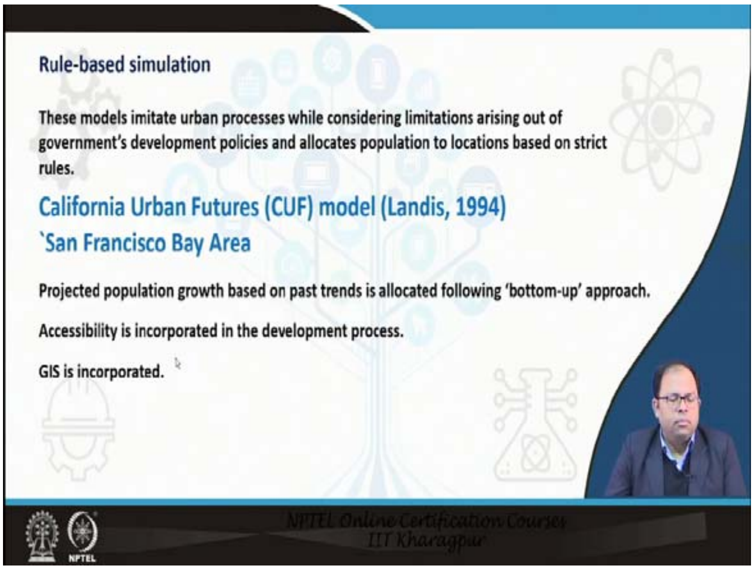

Rule based simulation models

Rule based simulation models imitate the normal urban development processes while considering limitations and restrictions arising out of government's development policies (like restrictions to build in wetlands) and allocates population to locations based on strict rules. The model traces land development undertaken by real estate developers through identifying potential lands for development and their profit potential while considering existing government regulations. The population is allotted to these developed lands.

California urban futures model developed by Landis in 1994 is the most famous rule based simulation model. This model was applied in the San Francisco Bay area. The projected population was based on past trends and was allocated following a bottom up approach i.e., the population is first predicted and then we gradually allocate them to different zones considering zonal accessibility. GIS is also an integrated part of this modeling process.

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The image shows the structure of the California urban futures model. In step 0, basic employment growth by county is forecasted. This is an exogenous input taken into the model. Next, is the bottom-up population growth sub model. The city population and the county population are projected for 5 year periods. Next, the unincorporated population growth (people who have not been allocated a land) are considered for land allotment. GIS maps and spatial databases are developed/updated with new information on laws, administrative boundaries etc.

Next, developable land units(DLU) in a particular area are determined based on the available information. These are the land units which could be developed by real estate developers. Then, the profit potential for each of these units are determined. Units where there is chance of loss and other laws preventing development are eliminated. Then, the population is allotted following the profit potential of each of these DLUs. Allocation of the population results in a new land use.

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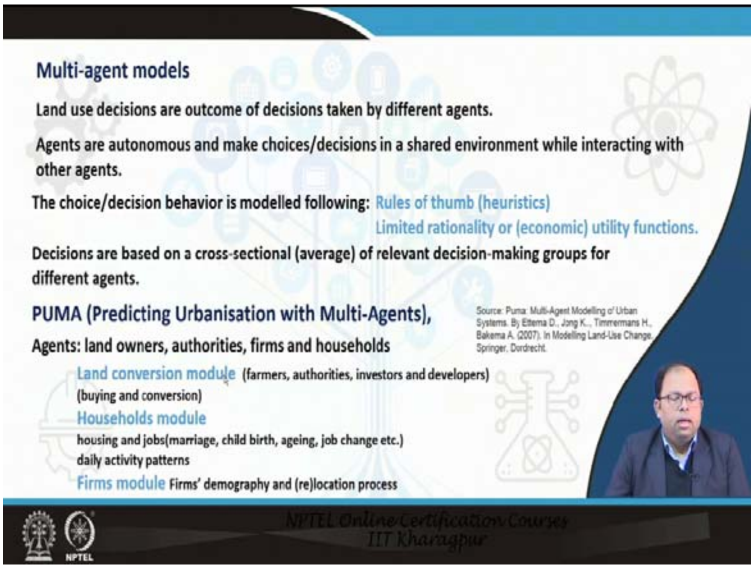

Multi agent models

In multi agent models, all the different decisions related to land use are considered as an outcome of decisions taken by multiple agents. These agents can be households, firms, or could be a model component which determines land price or car ownership. These components or agents are autonomous and they make choices or decisions in a shared environment while interacting with other agents. This choice/decision behavior is modeled following rules of thumb/ heuristics, or limited rationality/ utility functions. Utility functions refer to discrete choice that we have discussed earlier. The term limited rationality is used since everybody do not get/have information about all the choices and whenever a person takes a decision even though it is based on rational behavior, it is limited to a certain extent. Decisions are also based on a cross sectional average of relevant decision making groups for different agents.

Using utility functions and discrete choice theory, the decision could be taken by an individual or could be taken by a group. In case, a group is homogeneous, then the decision taken by that group is same for all the individuals/households/firms that belong to that group. So this is why cross sectional average of relevant decision making groups are considered while determining the probability of a choice.

PUMA is a well-known multi agent model which is still in use. The main agents or components included in the model are a land conversion module, a household module and a firm module. The land conversion module allows buying and conversion of a particular land and involves farmers, authorities (planning department, municipal corporation etc.), investors and developers. The household module is used for determining household location choice for housing and location choice for job. Additionally, transition of the household is also tracked in terms of marriage, childbirth, ageing, job change and so on. Daily activity patterns are also determined based on which, the number of trips that are generated from each household is determined. Finally, in the firm module, the firms' demography and relocation process is also modeled. These agents and modules are connected to each other and they interact with each other. The agents also take certain decisions which follows limited rationality resulting in a particular choice, which ultimately determines the spatial structure of a particular urban area.

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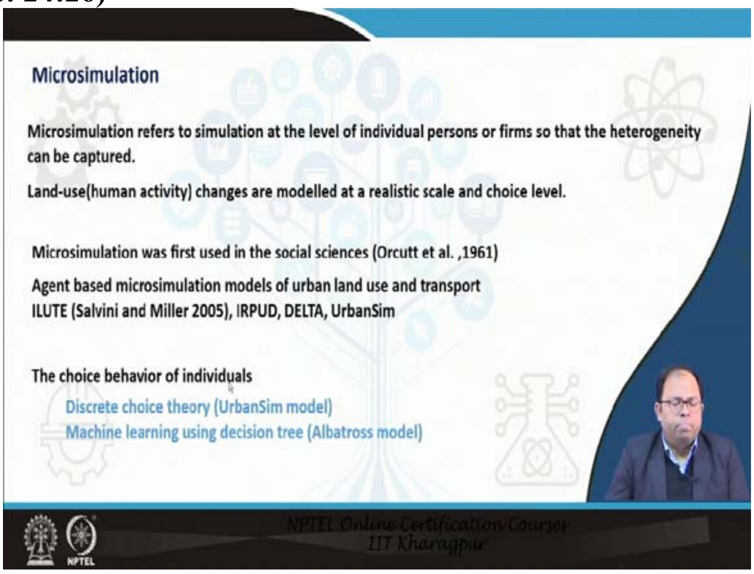

Micro simulation model

Micro simulation refers to simulation at the level of individual persons or firms which helps in capturing the heterogeneity. Thus, instead of taking homogeneous groups, every individual/entity is considered assuming that the decision making process of each individual/entity is different. Thus, land use and human activity changes are modeled at a realistic scale and choice level.

Decisions taken at individual level when added up results in more realistic outcomes. Micro simulation was first used in the social sciences discipline. Agent based micro simulation models of urban land use and transport are also being developed and some of the widely used models are ILUTE, IRPUD, DELTA and UrbanSim.

The choice behavior of individuals is modeled following the discrete choice theory as in the case of the UrbanSim model and also following machine learning algorithms such as decision trees in the Albatross model. Urban land use transportation models are currently and gradually moving into the domain of machine learning to predict choices.

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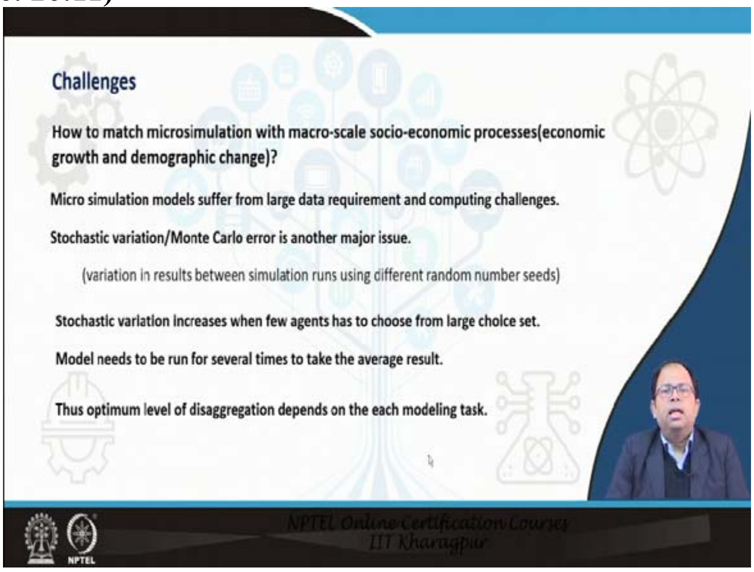

Challenges of micro simulation

Incorporating decision of individual persons or firms in regards to their location and transportation choices in an urban area using micro simulation results in a more appropriate, realistic, predictions which are more near to the actual conditions. However, not everything can be conducted at a very micro scale. For example, economic growth and demographic change are predicted at a macro scale and cannot be done at a micro scale. Thus, matching the regional population and jobs forecast which are at a macro scale with micro scale choices (individual level) or micro scale location allocation (plot level) in a particular urban area is a challenge people face when developing and using micro simulation models. Micro simulation models also suffer from large data requirement and computing challenges.

Next, is stochastic variation or Monte Carlo error, which is another major issue. Whenever, an individual is making a choice, a discrete choice model is used to determine the probability of the choice. However, this individual has to be allocated a fixed choice in the simulation which is when Monte Carlo process is used. This will be explained in detail in a later chapter. In short, random numbers are used to determine an individual's final choice based on the probability determined using the discrete choice model. However, different random number seeds (seed is basically the starting of the random number) results in different results/final choice. Thus, every time the model is run, the results will vary. This difference is little but still it exists and leads to the next question i.e., If the model predicts differently every time, which result should be considered? One solution is to run the model several times and then take average of the results to determine the final result or outcome, either for land use or transportation processes.

Another problem resulting from stochastic variation is when; there are less number of individuals and more number of choices. When few firms have multiple option to choose from, for example the location of new office from multiple plots, then the results vary at different runs and this can lead to a lot of variation in the final result.

These are the basic problems of micro simulation approaches. Even so, micro simulation is more robust compared to the other approaches. Thus, the optimum level of disaggregation can also depend on each component of the model.

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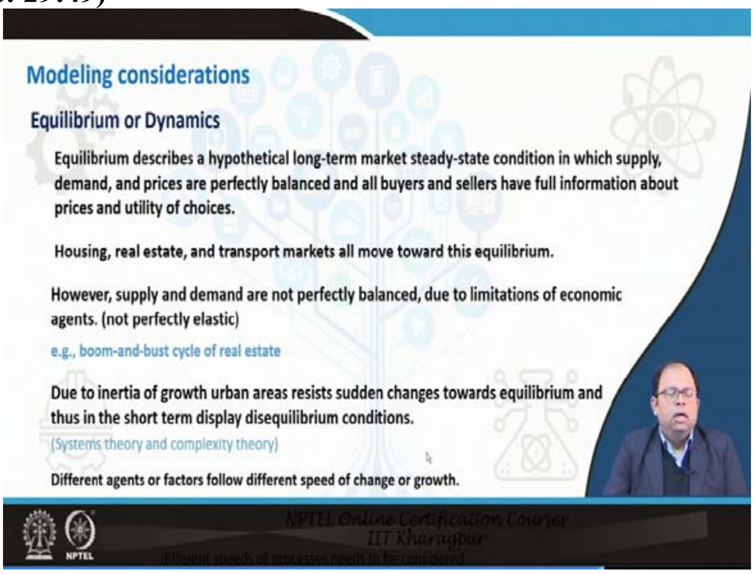

Modeling considerations

Along with the different modeling approaches, there are few modeling considerations which are also very, important.

Equilibrium or dynamics

One such modeling consideration is equilibrium or dynamics. Equilibrium describes a hypothetical long term market steady state condition in which supply, demand and prices are perfectly balanced and all buyers and sellers have full information about prices and utility of choices. Thus while, allotting households and firms to an area it is assumed that supply of land or building matches equally in a certain time period. But in real life, it is different. This is because when a developer realizes that, there is a market potential for development for a particular kind of real estate in a particular area, then he will choose to develop the same, but, it takes certain time for that property to be available in the market thus resulting in a time lag of few years. This means that, during this time there is a shortage of supply which will increase the prices resulting in lowering of demand. On the other hand, whenever a new developer completes and offers a property/project, he actually supplies more than what is required in the market. This is because, the developer knows that there will be adequate demand eventually and because of the characteristics of that particular development, i.e. the developer has no option but to do the entire property development all together. These situations lead to instances of under and over supply which is also known as boom and bust cycle in real estate.

Thus, even though, housing and real estate and transport market all moves towards equilibrium, supply and demand is not perfectly balanced, which is due to the limitations of the different agents and because these agents are also not perfectly elastic. This results in a time lag for demand to match supply and supply to match demand. Besides, due to inertia of growth of urban areas, sudden changes towards equilibrium are also not possible.

This short term disequilibrium conditions in an urban area can be also explained by the systems theory and the complexity theory. Since, there are so many small systems in an urban area with each influencing one another, suddenly an entire urban area cannot be in equilibrium. Thus, disequilibrium conditions always exist and have to be considered in the urban modeling process as well. Thus, assumptions of equilibrium for a long period may be true for a short period it is most likely wrong. Different agents in an urban area grow/change at different speed. For example, it takes three years to build a house, whereas, a person changes house after a certain period which is much longer than three years and a building lasts for fifty years or more. Thus, different factors/agents have got different life cycles and accordingly, we can also choose the time for the modeling process.

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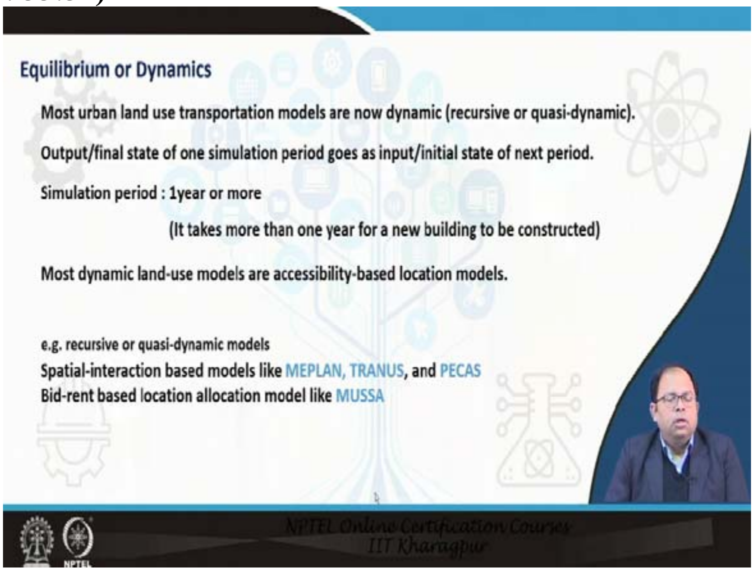

Most of the urban land use models and processes currently developed are made little bit dynamic which can be also called recursive or quasi dynamic. Thus, instead of having time periods of 10 years as prediction periods, model outcomes are predicted every 1 year (can be even 5 years) and then the model is run again taking the output of the first year as the input for the next year.

While, most of these dynamic land use models are based on accessibility based location choice models, some of these models are based on the spatial interaction theory such as MEPLANS, TRANUS and PECAS. These models were initially not dynamic, but have been currently converted into dynamic models. Similarly, bid rent based location allocation models like MUSSA, have also been converted into a dynamic model.

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Macro and micro

Micro and macro refers to the level of spatial and substantive disaggregation i.e., the appropriate size of analysis. Unlike in the TAZ level analysis, in micro simulation, a particular firm or an individual chooses a plot or housing unit respectively. This necessitates going to the micro scale. As shown in the in the image, two grids can be considered, one a 1000 x 1000-meter grid which is the larger grid and within that a 150 x 150-meter grid. Next, detail information is required at this micro grid level such as number and other details of housing units and eventually a household is allotted to this grid. The allocation can be random but as per his income group. Thus, the characteristics of this particular unit/grid influences his choice for moving into this unit which is again determined based on the number of empty housing of a particular category or the kind of characteristics this particular unit or area possesses e.g., access to the highway, predominant landuse (residential or commercial), density etc. At the TAZ level, it is difficult to generalize these characteristics or form the utility value/equation, which would apply homogeneously to all plot of land or to a particular individual. Thus, there is a need to move from macro to micro scale. While, earlier models are mostly zone based, but since 1990s land use change is modeled using high resolution grid cells. This is mostly for US and Europe and other developed nations. Micro simulation and activity based models require this high level of location data which is obtained by combining data from different sources.

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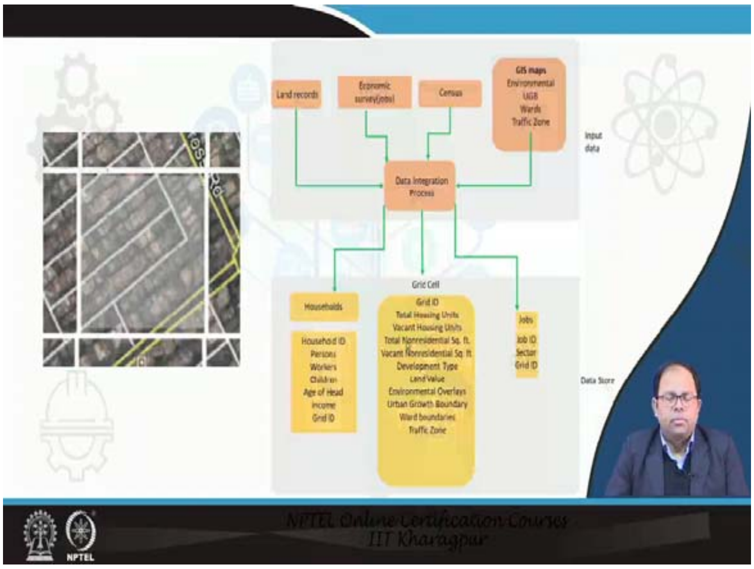

The different characteristics(data) of a micro grid that are usually required are land records that shows plot sizes, plots which are empty and other relevant information, economic survey data including number of jobs available, census data on number of households living in a particular grid etc. In case detail data is not available, data from a broader region within which this particular grid belongs can be used either considering simple proportions or using other advanced techniques which will be discussed later. Existing GIS maps can be used for environmental information, urban growth boundaries, ward boundaries, traffic zones etc. which can be extracted and integrated to create the characteristics of the grid.

In addition, a database/list is maintained for each grid for different kinds of jobs belonging to different sectors with each job having an ID so that when it is filled the same can be recorded during the modeling process. Similarly, each household is assigned an ID which can be used to determine the household size, number of workers, number of children, household income. Vacant housing units, vacant plots and land value is similarly tracked and updated.

Collecting and maintaining this kind of data for grids like 150 x 150 meter is challenging and the basis of the macro versus micro debate.

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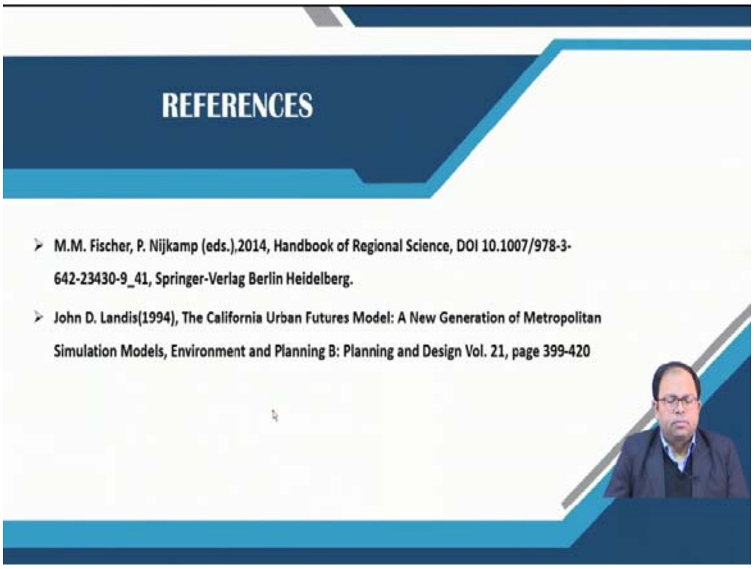

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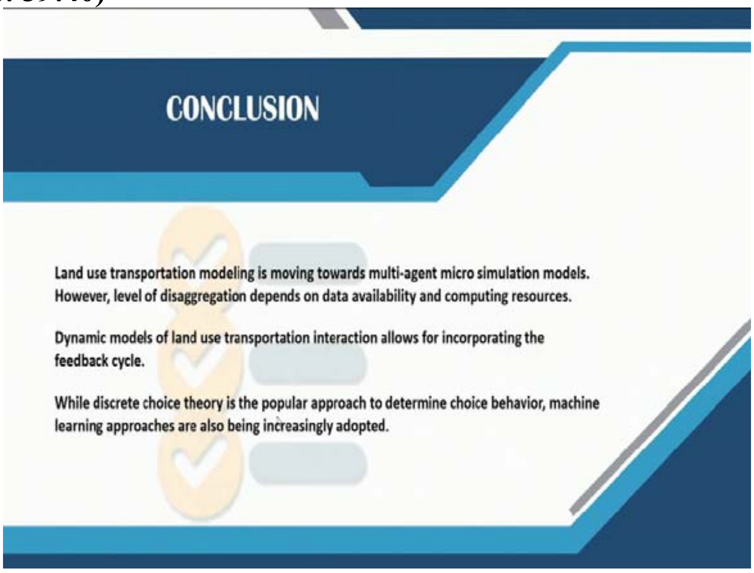

Land use transportation modeling is moving towards multi agent micro simulation models. However, level of disaggregation depends on data availability and computing resources.

Dynamic models of land use transportation interaction allow for incorporating the feedback cycle.

While discrete choice theory is the popular approach to determine choice behavior, machine learning approaches are also being increasing adopted.

This chapter gives a broad idea about the different modeling approaches that are undertaken in a urban area.

Thank you.